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Color Temperature Meter

Comparison of Recording Processes

Magnetic Recording Equipment

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American Standard

International Standardization

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Basic Principles of the Three-Dimensional Film

By RAYMOND SPOTTISWOODE, N. L. SPOTTISWOODE and CHARLES SMITH

Professional three-dimensional (3-D) film productions cannot be satisfactorily undertaken without a comprehensive theory of the transmission of an image in space from scene to screen. In Part I the outlines of such a theory are laid down, and the elements of a standard set of concepts and nomenclature put forward. Part II draws an example from a recent film, *The Black Swan*, to show how the stereotechnician computes a sequence of shots in the desired space relationship, and how simple graphical techniques may be employed to plot such relationships. From these graphs may be determined the magnitude of any postcorrections required to alter the continuity in space, to adjust the film to screens of widely differing size or to eliminate certain camera errors. Part III forms a critique of existing camera procedures, including those based on the supposed identity between human vision and the viewing of the space image. Part IV sums up the differences of technique between the flat film and the 3-D film.

Up to now the production of three-dimensional (3-D) films has been sporadic — scattered all over the world and separated by long intervals of time. Most of the practical information available was to be found in papers by the American pioneer, J. A. Norling, which were read before the Society;[1] but these dated from before World War II and applied to films of rather limited scope.

A contribution submitted July 21, 1952, by Raymond Spottiswoode, N. L. Spottiswoode and Charles Smith, Stereo Techniques, Ltd., 36, Soho Square, London, W.1., England. This article is an adaptation of part of the forthcoming book, *The Theory of Stereoscopic Transmission*.[4]

More recently in England, the Festival of Britain afforded an opportunity to produce a varied program of stereoscopic films; these too have been described in outline in the *Journal*.[2,3] Production did not stop at this point, however, for a further series of films was initiated for commercial distribution starting in the early summer of 1952. Both these programs were based on the same body of technical principles; both were the work of the same groups, one in Canada for the animation films, the other in Britain for the studio and actuality films. By the completion of the second program, therefore, with an output of about a dozen films, much production experience had been

gained and knowledge accumulated on the ways in which audiences see and react to this new kind of film. The present paper is an attempt to summarize a part of this knowledge in the hope that it may be of value to American producers who are experimenting in the 3-D medium. To make the theoretical part of the treatment more concrete, we relate it in an extended example to a particular film completed a few months ago.

A 3-D Ballet Film

The presentation of our Festival program at the Telecinema drew many requests for a stereoscopic ballet — a subject notoriously difficult to film satisfactorily in the ordinary way. We therefore decided to produce a ballet film for 1952, even though time did not allow of special choreography to take fullest advantage of the dimension of depth. Our final choice fell on an episode from Tschaikovsky's *Swan Lake*, which made a story complete in itself within the limits of 13 minutes of film, and enabled us to feature two of the star dancers of the Sadlers Wells and Covent Garden companies, Beryl Grey and John Field.

Shooting was to be limited to four days on the studio floor, and this meant careful preplanning of stereoscopic effects in relation to the script. For this purpose it was essential to know how the dancers were to move in relation to the movements of the camera, which was to be mounted on a crane in the interests of complete fluidity. There was, however, a formidable problem to contend with which has no counterpart in the making of ordinary films: namely, to control the position in space in the ultimate movie theater of each scene occurring in space before the camera. The continuity might demand a smooth spatial transition between one shot and the next; or there might have to be an abrupt impact of something presented much nearer to the eye or much farther away than the audience would expect. Examples of both types of "continuity in space" abound in this film. Again, from shot to shot it would be necessary to adjust the camera to the precise range of distances in the scene before it; and if any errors occurred at this stage, it must be possible to determine and correct them by optical printing. Finally, in the interests of strain-free viewing, it was essential to be able to take into account all those factors which affect the fusion of the images, and whose neglect in the past has often led to eye fatigue and has tended to give 3-D films a bad name among the public.

There is no way of achieving this assured control over the image throughout its progress to the movie theater except by having at one's command a complete knowledge of the stereo transmission system between camera and spectator. Fortunately, long before the shooting of *The Black Swan* was attempted, such a transmission theory had been worked out, and a full account of it will shortly be available to American readers.[4] Nonetheless, some attempt must be made here to indicate the nature of the problems and the lines along which they can be solved.

PART I: THEORY

As is well known, all commercial stereoscopic film systems of today are of a type which may be called *plano-stereoscopic:* that is, the constituent optical images from which the depth image is formed by binocular fusion are projected on a surface, the screen. In large-screen projection, these optical images are superimposed, and must be sorted out by each spectator with the aid of individual viewing devices, which are normally of polarizing material. It is thus necessary to start with an analysis of the way the spectator sees the picture in space, after

which we can work back through the projection and production processes to the camera which is to be controlled on the studio floor.

Psychological Viewing Factors

In the spectator's mind two altogether different sets of impulses are at work. The binocular faculty attempts to place objects in space by methods which are still imperfectly understood in their entirety, but which may for simplicity be likened to the working of a rangefinder. At the same time, other departments of the mind are busy observing all sorts of other clues to depth and position in space. There may well arise conditions when these two sets of data will conflict, leading to an ambiguity in the image which different people will resolve differently — much as two people may sit down before a Picasso canvas in the Museum of Modern Art and come to wholly different conclusions as to what it is all about. Even more serious difficulties will arise if the conflict is so fundamental that the spectator cannot bring himself to believe in the stereoscopic data. A scene may be brought forward to a certain plane in space, but will not in fact appear to be there because the audience cannot accept the fact that a dining room table or a ballet dancer is poised in space over the front rows of the stalls. This effect has been known for many years, and is well analyzed in a classic paper by Professor J. T. Rule.[5]

The planning of our stereoscopic films does of course take account of these and many other psychological factors; and we hope, if interest in the 3-D film continues active, to discuss in a later paper a number of new ways of bridging the remaining gap between audience and space film. In the present paper we shall confine ourselves to considering the physical elements in the stereoscopic transmission system, since these have been the subject of much fruitless debate, which it is time to try and replace with an agreed nomenclature and method of mathematical approach.

The Mechanics of Viewing

The elements of a plano-stereoscopic projection system, with image separation at the spectators' eyes, are sketched in Fig. 1. A generalized spectator is shown, placed at a distance, V, from the screen, onto which have been thrown left- and right-eye images. It is convenient to consider these images as consisting of a multitude of separate points, much as is often done in discussions of film resolving power. In general, to each point on the left-eye image there will be some corresponding point in the right-eye image, both image points having the characteristic that they represent the same object point in the original scene.* These image points are sometimes called *homologous points*, and they are represented in Fig. 1 by L and R.†

The eyes are shown as having a separation, t, this letter also being used in our nomenclature to denote the lateral separation of optical axes, suitable subscripts being used to distinguish the camera and projector. Through their selecting viewers, the eyes regard separately the left and right members of each pair of homologous points on the screen, whose horizontal separation is known as *parallax*. Parallaxes are always denoted by

* Note that the original object may be imaginary, as in 3-D abstract and cartoon films.

† It is noteworthy that, in a projection system such as we are discussing, the eyes are able to prompt the mind without any additional clues as to which pairs of points are to be considered homologous; occasional errors — as in the fusion of wire mesh and wallpaper patterns — occur also in binocular vision and are of negligible importance in practice. On the other hand, some types of integral screen, which dispense with viewers for seeing 3-D films, require the transmission of information as to which points are homologous, and are therefore "information-consuming" and wasteful.

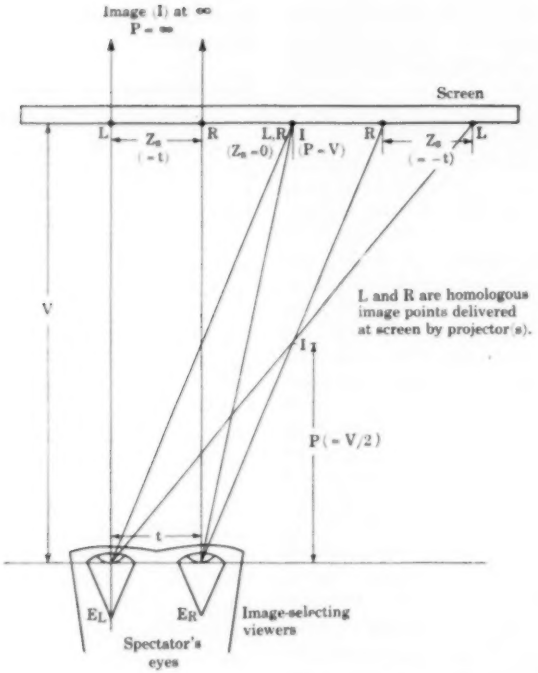

Fig. 1. Construction of a space image point (I) from optical image points, L and R. A spectator's eyes, E_L, E_R, having a lateral separation, t, are equipped with selecting viewers and regard, respectively, left and right corresponding image points, L and R. These are separated on the screen by a parallax, z_s, which may be positive or negative. The spectator, distant V from the screen, will see the fused image point, I, at the intersection of the rays from E_L to L, and E_R to R. His distance from I is denoted by P.

the letter z, a subscript being added to distinguish the kind of parallax referred to. Thus a screen parallax is z_s, a parallax on the projected film z_p, a parallax introduced by displacement in the optical printer z_d, and a parallax originating in the camera z_c.

Three special cases are shown in Fig. 1; (a) that in which $z_s = t$, for which rays of light are reflected parallel from the screen, so that the image point is placed at infinity; (b) that in which $z_s = 0$, in which the point is imaged in the plane of the screen (whence it follows that a normal flat film is merely a special case of the 3-D film, that in which $z_s = 0$ for all image points); and (c) that in which $z_s = -t$, and the image, as may be seen from simple geometry, is halfway out to the spectator.

From previous theoretical discussion, the impression has got around that stereoscopic projection is extremely complicated, requiring special and often vari-

able alignment of the projectors, and an analysis of keystone distortion, optimum lens focal length, and so forth. Projectors, however, are much better regarded as fixed mechanisms, which cannot be swiveled or otherwise adjusted from shot to shot. Furthermore, image distortion arising from projection is no more objectionable in a 3-D than in a flat film, and can safely be relegated to the background as a second-order problem,* provided that no additional distortion is caused by beam-splitting or other methods.

Hence it is only necessary to agree on the parallax at the screen between the left-eye image, regarded as a whole, and the right-eye image regarded as a whole. The alignment which we have adopted is that which differs least from the standard alignment of projectors for flat films, namely, one in which the image centerlines are superimposed. This can be succinctly expressed as $z_{CL} = 0$. Some consequences of altering the value of z_{CL} are discussed later in this paper.

With t, the spectator's eye separation, substantially constant at 2.5 in., and with z_{CL} assumed equal to zero, only two projection factors need to be considered: V, the spectator's distance from the screen, and M, the linear magnification which the image undergoes from film to screen.

The Nearness Factor

Referring again to Fig. 1, we can now advance to the first useful generalized concept, which appears not to have been remarked on before, though it is essential to any clear discussion of the production of 3-D films. It may be stated quite generally that, *for any pair of optical image points, the ratio of the spectator's viewing distance* (V) *from the screen to his distance* (P) *from the fused image point is a constant, no matter whereabouts in the theater he may be sitting.*

This ratio we call the *nearness factor* (N) of the image point, and we may therefore write,

$$\frac{V}{P} = N \qquad (1)$$

It is apparent that,

if $P = \infty$, $N = 0$ (image at infinity),

if $P = V$, $N = 1$ (image at the screen plane),

if $P = \frac{V}{2}$, $N = 2$ (image halfway out to spectator), and so on.

We can therefore state unambiguously for the first time where we wish a certain object in a studio set or on location to appear in space to the spectator in the movie theater.* If the director says that he wishes an actor seated at a table to be represented at $N = 0.5$, while another's hand, outstretched toward the audience, is to be at $N = 4$, the stereotechnician knows at once that each spectator is to see the first actor at twice the viewing distance to the screen, whereas the other's hand must come out from the screen three-quarters of the way toward him. The concept of the nearness factor is easily grasped, even by studio personnel to whom the rest of the stereo shooting procedure remains something of a mys-

* Projector separation, t_p, inevitably produces some second-order distortion due to keystoning. This is analyzed fully in Reference 4, together with some attendant anomalies of vision which help to rectify the shape of the image.

* In 1856, Sir David Brewster, writing about the wire mesh and wallpaper phenomena mentioned above, gave numerical data from which the constancy of N with change of viewing distance can be correctly inferred.[6] But he failed to generalize the concept of the nearness factor, no doubt because of his preoccupation with the problems of individual viewing. (It must be remembered that, prior to the invention of the incandescent lamp, only very rudimentary means were available for projection to large audiences.) Nonetheless, Brewster was far ahead of his time, and his book is even now worth reading.

tery; but it affords the connection of ideas most necessary to establish between director and stereotechnician.

Object Distances and Image Distances

Next we must see how the position of the camera in front of the scene is related to the image of that scene in front of the spectator. Denoting by d_n the distance from the camera to a given object point, there will be a corresponding image point seen by a spectator in the theater as having a nearness factor, N_n. Specifically, we may refer to an image point at N_0 (infinity) deriving from an object point at d_0, an image point at N_1 deriving from a point at d_1, and so on.

Now if we were to graph the distance of object points d_0, d_1, d_2 . . . against the actual distance, P, of the corresponding image points from the spectator, it must not be supposed that the result would necessarily be a straight line. This represents an important but entirely special type of stereoscopic transmission; that is to say, one in which the rendering of distance is a linear function. We shall meet this again later on, but it is worth observing here that linear transmission does not of itself produce an *orthostereoscopic* image, or one which is geometrically congruent with the original scene. There may be a multiplying factor either greater or less than unity by which a given length is stretched or shrunk, though of course uniformly throughout the scene.

A New Unit: The Rho

We now come to the problem of relating d_0, d_1, d_2 . . . in the scene to N_0, N_1, N_2 . . . in the theater. Here another important step forward has been taken in the simplification of stereo calculations by introducing a new unit of distance. It can be shown that *if a reciprocal distance unit is employed, equal numbers of depth units in the scene will always correspond with equal changes of nearness factor in the cinema, no matter whether the transmission system is linear or nonlinear.*

Thus at one stroke a mass of difficult computation is done away with, and depth ranges in the scene can be manipulated by simple arithmetical addition and subtraction.

The new distance unit has been named a *rho* ("reciprocal" denoted by the Greek letter ρ), and to bring it to a convenient size it is defined as the reciprocal of the distance in inches multiplied by an arbitrary constant, the ρ constant (K), which has been set at 6,000. Thus we may write

$$\text{distance in } \rho = \frac{6{,}000^*}{\text{distance in in.}} \qquad (2)$$

This is equivalent to 500 divided by distance in feet, and the units of course decrease with increasing distance, and vice versa, as is shown in Table I.

Table I

Distance	ρ	Distance	ρ
100 ft	5	6 ft	83
50	10	5	100
33	15	4 ft 6 in.	111
25	20	4 2	120
20	25	4	125
10	50	3 4	150
7	71	3	167

Whereas distances in linear units are expressed as d_0, d_1, d_2 . . ., the corresponding ρ distances are designated D_0, D_1, D_2 . . . . All measurements on the set and on location are made with a tape graduated in ρ on one side and in feet and inches on the other, for focusing. (In passing, it is worth noting that if lens-focus scales were engraved in ρ, they would be calibrated with equal separations for equal ρ differences, in place of the present unequally divided scales. Furthermore, depth of focus tables would need only one entry under each focal

* Because of the superior convenience of a decimal system of linear units, we have recently converted to the metric system. 1 metric ρ = 10,000/distance in cm.

length and aperture setting, instead of a multitude of entries relating to all possible focus distances. But to gain these worth-while advantages, camera assistants would have to train their minds to udge distances nonlinearly, which would no doubt prove difficult!)

In order to indicate how the general equation is derived, which connects the distance of objects in the scene with the distance of their corresponding images in the cinema from the spectator, it is necessary to return for a moment to the cinema and re-examine the parallaxes on the screen (z_s). Referring again to Fig. 1, and adopting the sign convention that uncrossed parallaxes are positive and crossed parallaxes negative, we can see at once that

when $z_s = t$, $P = V/0$, i.e., image at N_0 (infinity)
$z_s = 0$, $P = V/1$, i.e., image at N_1 (plane of screen)
$z_s = -t$, $P = V/2$, i.e., image at N_2 (halfway out)
$z_s = -2t$, $P = V/3$, i.e., image at N_3 ($\frac{2}{3}$ of way out)
$z_s = -3t$, $P = V/4$, i.e., image at N_4 ($\frac{3}{4}$ of way out), and so on.

Note: In our standard terminology, the letter t always represents the lateral distance between two optical axes, t itself denoting the separation of the human eyes (here assumed throughout as 2.5 in.), t_c the separation of the camera optical axes, t_p that of the projector optical axes, etc.

In other words, equal negative increments of parallax produce equal increases in N value. Moreover, these parallaxes are absolute; that is to say, they derive only from factors which are constant for any observer sitting in a given position in the cinema. They are irrespective of the size of the screen. But the corresponding parallaxes on the projected film, z_p, are related to the screen parallaxes, z_s, by an optical magnification, M, which will be greater or smaller according as the screen is wider or less wide. Stated the other way round, a parallax of given magnitude on film will produce a greater or lesser stereoscopic depth according as the screen is larger or smaller. This important influence of screen size was first clearly stated, and its effects remarked on, by Professor Rule in the paper already cited.

Depth Content in the Theater

At this stage it will help to introduce another concept, that of the *depth content* of the film in the cinema; in other words, the range of depth in space which the image occupies. Let us assume a difference in nearness factor of 2 between the front and rear planes of the image, which we shall express as $^{\Delta}N_2$. Normally the range of N values would be from N_0 (infinity) to N_2, but from the point of view of the parallax analysis which follows, the position of the N range in space is immaterial. For example, $^{\Delta}N_2$ might correspond to the range N_1–N_3, as in the recent McLaren cartoon film, *Twirligig*.

Now it is apparent from what has been said that

$$z_p = \frac{z_s}{M} \qquad (3)$$

Since a change in N value of 1 results from a change of screen parallax of t, a depth content of $^{\Delta}N_1$ corresponds to a parallax on the projected film of $2.5/M$ in., a depth content of $^{\Delta}N_2$ to $5/M$ in., and so on.

Magnitude of Film Parallaxes

In order to give a more concrete idea of the magnitude of the actual film parallaxes when shooting for screens of normal commercial size, it may be helpful to deviate for a moment from the main course of the argument. Table II has been prepared to show the total span of film parallaxes available (in mils) for films

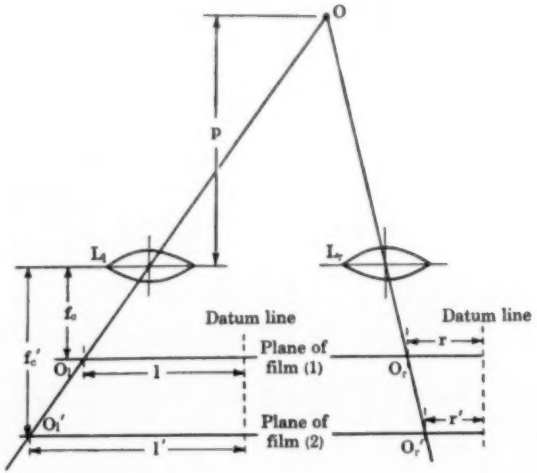

Fig. 2a. Relation between camera film parallax (z_e) and lens focal length (f_e). Object point O, distant p from camera, is imaged on film at O_l, O_r, through lenses L_l, L_r, of focal length f_e; and at O_l', O_r', with lenses of longer focal length f_e' (film plane shown schematically as being moved back). Parallax ($l - r$) measured from identical datum lines (e.g., guided edge or perforations).

When $f_e' > f_e$, $l' - r' > l - r$
When $f_e' < f_e$, $l' - r' < l - r$

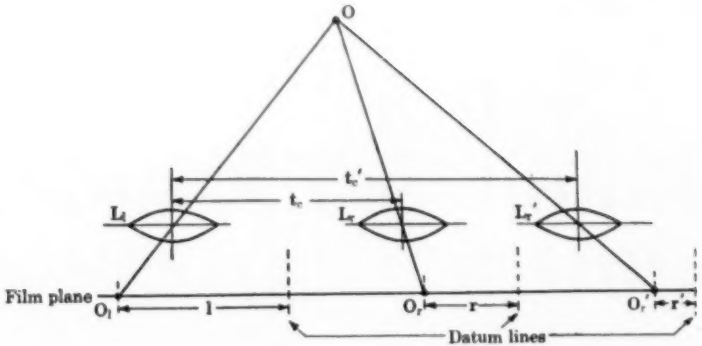

Fig. 2b. Relation between camera film parallax (z_e) and lens separation (t_e). Object point O is imaged on film at O_l, O_r, through lenses L_l, L_r, having a separation t_e, and through lenses L_l, L_r' having a separation t_e'. (Parallax measured as in Fig. 2a.)

When $t_e > t_e$, $l - r' > l - r$
When $t_e' < t_e$, $l - r' < l - r$

Table II

Magnification (M)*	Screen Width (W)	Total projected film parallax, z_p (mils) for ΔN_1	ΔN_2	ΔN_3
200	13 ft 9 in.	12.5	25.0	37.5
250	17 2	10.0	20.0	30.0
300	20 8	8.3	16.7	25.0
350	24 1	7.1	14.3	21.4
400	27 6	6.25	12.5	18.75

* Based on the standard 35-mm projector aperture width, 0.825 in.

employing depth contents of ΔN_1, ΔN_2 and ΔN_3. The ΔN_1 column is of interest merely because there remain some conservative spirits in the 3-D film field who think that no action should take place in front of the screen plane.

In realizing a given depth content in the cinema, there is however another factor to consider. The representation of a given depth space may be imagined as built up of an infinite number of infinitely thin planes. Were this achievable, we might say that the *stereoscopic resolving power* was infinite, for the system would have an infinite capacity to discriminate depth. In actual practice, however, these planes will be replaced by more or less shallow zones, within each of which a position in depth will not be accurately reproducible. The depth of the zones will therefore be a measure of the stereoscopic resolving power of the system. These zonal depths may conveniently be denoted by the change in nearness factor, δN, which they represent, and we accordingly employ the concept of δN to clarify discussions of resolving power, without suggesting that this will necessarily be the unit finally accepted.*

Assume, then, that any volume of space denoted by ΔN_1 is to be representable in 10 zones of depth; in other words, $\delta N = 0.1$. We can then tabulate the minimum film parallaxes which it will be necessary to have recorded reproducibly on the projected film — that is, after taking into account all possible random parallactic errors in previous stages of the transmission system.

* Experiments are being undertaken with trained observers to determine whether δN, δP or perhaps some other concept corresponds best with the subjective impression of depth resolution.

Table III

M	Minimum values of z_p (mils) for $\delta N = 0.1$
200	1.25
250	1.00
300	0.83
350	0.71
400	0.63

Note: The bracketed range comprises approximately 67% of existing motion picture theaters, as revealed in the recent SMPTE survey.[7]

Table III shows that, for screens found in the majority of commercial theaters, the minimum reproducible film parallaxes needed to achieve a depth resolving power of 0.1 do not much exceed the dimensional tolerances of the film itself, let alone allowing for shrinkages which may occur at intermediate stages in commercial laboratory practice, or for mechanical errors in the stereoscopic adjustments of the camera. The need for extreme precision is still further emphasized by the fact that $\delta N = 0.1$ is equivalent to only 20 separable zones in space for a normal 3-D film having a depth content of ΔN_3.

The General Equation

Reverting to our main theme, it will be evident that the greater the magnification, M, the greater the screen parallax to be derived from a given film parallax. Turning to the camera, it can be seen from Fig. 2 that an object point at a given distance produces a greater film parallax, (a) the longer is the focal length, f_c, of the camera lens(es), and (b) the greater is the lateral separation, l_c, of the lenses or optical systems. Thus an increase in these three factors, M, f_c

and t_c, increases the final parallax on the screen, whose absolute magnitude determines the N value of the image point corresponding to the original object point, O. In fact the product $Mf_d t_c$ is combined into what is called the *C factor* in our general equation.

This equation, which will be stated but not derived here, expresses the distance, P, of a fused image point from the spectator in terms of the distance, p, from the camera of the original object point, together with the other variables of the transmission system.

$$P = \frac{Ap}{C - Bp} \tag{4}$$

Thus, besides M, f_d, t_c and p, which we have already mentioned, there is an A factor and a B factor. The *A factor*, Vt, is a function of the spectator and his viewing distance from the screen, as may be seen from Fig. 1. The *B factor* denotes an important transmission concept, which is governed by the convergence of the camera optical axes (or its preferable equivalent, inward lateral displacement of the lenses relative to the films).

The B factor can be related to a camera convergence half-angle, φ, and a projector convergence half-angle, θ, as follows, taking account of the fact that an optical printing displacement, z_d, may have been introduced between the camera film and the projected film:

$$B = t_p - t + 2M(f_c \tan \varphi - f_p \tan \theta + z_d) \tag{5}$$

If lens displacement is employed instead of toe-in in the camera, h, and projector, H, we may write instead,

$$B = t_p - t + 2M(h - H + z_d) \tag{5a}$$

As a transmission factor, B may be very much more simply defined. Let ${}^{\infty}z_s$ denote the screen parallax of a point which was at infinity in the scene, i.e. at D_0. Then

$$B = {}^{\infty}z_s - t \tag{6}$$

Expressed in words, B is the excess of screen parallax of a point originally at infinity over the separation of the human eyes.

B+, B = 0 and B− Transmission

Three important cases now arise: that in which B is positive, that in which it is zero, and that in which it is negative. The discussion of the three types of stereoscopic transmission system will help to clear up the vexed question of camera convergence, a subject on which much ink has been spilt in the effort to establish as fundamental relationships what have been only rough-and-ready rules. Several of these are now being purveyed by inventors in France, Germany and Holland, but on investigation they are found to be merely crude approximations, the errors in which may be masked by the fact that they have been applied only to films projected on very small screens.

Figure 3 shows in graphical form the principal characteristics of $B+$, $B = 0$ and $B-$ transmission systems. It is to be noticed that both axes are scaled in a reciprocal type of unit, the x-axis in terms of D, and the y-axis in terms of N. Hence the origin represents infinity on both axes. From Eq. (6) it will be seen that when $B = 0$, ${}^{\infty}z_s = t$. When, as here, the screen parallax of a point equals the eye separation, t, rays reaching the eyes will be parallel, as they are when reflected from points at infinity. In other words, infinity in the scene (see definition of ${}^{\infty}z_s$) appears at infinity in the cinema. Thus a $B = 0$ shot must be represented in Fig. 3 by a line passing through the origin, and no other type of shot can be so represented. Referring again to Eq. (6), if ${}^{\infty}z_s$ exceeds t, it must be that some point short of infinity in the scene produces on the screen a parallax equal to t (because a point *at* infinity produces a parallax greater than t). Thus, when B is positive, a point nearer than infinity in the scene will correspond on the screen with a point which tends to appear at infinity. On the other hand, if ${}^{\infty}z_s$ falls short of t, so that B is negative, it must

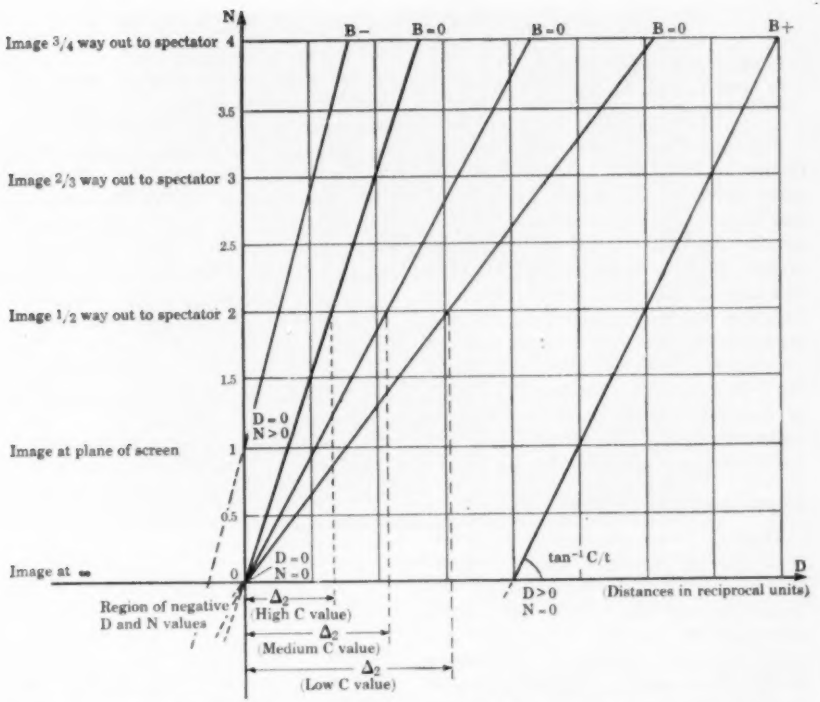

Fig. 3. The three types of stereoscopic transmission system: $B+$, $B = 0$ and $B-$.

be that a point situated at infinity in the scene will appear at some nearer distance in the cinema. All examples of stereoscopic transmission (in other words, all instances of 3-D recording and reproduction) must fall into one of these three classes, whose main characteristics may be exhibited thus:

Class	*Name*	*Characteristic*
$B = 0$	Ortho-infinite	Linear; infinity points correctly represented.
$B+$	Hyper-infinite	Nonlinear; objects short of infinity represented at infinity.
$B-$	Hypo-infinite	Nonlinear; objects at infinity represented closer than infinity; cardboarding.

In the example of a $B-$ system shown in Fig. 3, it will be noticed that infinity (i.e. $D = 0$) will appear on the screen plane, that is, at N_1. This will occur, for example, if a shot of distant objects is taken with the camera axes parallel ($\varphi = 0$), and projected with the projector axes toed-in so that the parallax of the aperture centerlines is zero ($z_{CL} = 0$). This frequently happens with amateur projection of stereoscopic stills and movies.

In short, the B factor can be varied at three stages in the production process, either angularly or by displacement, as follows:

	By toe-in	By displacement
In the camera	φ	h
By optical printing	—	z_d
By projection	θ	H

For ease of calculation, it is better to reduce all the stages to a displacement, using equivalences derived from Eqs. (5) and (5a). This also makes it possible to employ the simple graphical techniques of shot analysis described in Part II of this paper. Note that the effects of convergence and displacement (apart from second-order distortions in the case of convergence) are fully accounted for by the B factor alone. There is no problem of camera or projector axis alignment which cannot be very simply solved by the methods described here.

Depth Range in the Scene

Figure 3 illustrates another important idea, that of the *depth range* of a scene, which is defined as the range of distances corresponding to a given depth content in the cinema. The symbol Δ is used to denote a difference of D values, so that, for example, Δ_1 signifies a range of reciprocal distances which will produce a depth content of $^{\Delta}N_1$ in the cinema under given transmission conditions. Δ_1 may of course designate $D_1 - D_0$ or $D_2 - D_1$, and so on, as with its equivalent in the cinema, $^{\Delta}N_1$. It will be noticed from Fig. 3 that the depth range may be obtained from the depth content, or vice versa, by simple reflection through the appropriate characteristic curve, which will always be a straight line, no matter whether the transmission is linear or nonlinear.

These curves are based on the fundamental equation connecting reciprocal distances in the scene with nearness factors in the cinema. It is derived from Eq. (4) and can conveniently be written,

$$N = \frac{C}{t} \cdot D - \frac{B}{t} \qquad (7)$$

Hence the characteristic curves of Fig. 3 make an angle with the x-axis equal to

$$\tan^{-1} \frac{C}{t},$$

sloping more steeply therefore as the C factor increases. We have already seen that an increase in the C factor increases the film and the screen parallax of a given object point in the scene. Hence it will also increase the depth content, $^{\Delta}N$, in the cinema for a given span of depth range, Δ, in the scene. Or, to put this in a form more useful to the cameraman, the larger the C factor, the shallower will be the depth range in the scene for any given range of N values in the cinema. This is clearly shown in Fig. 3 by the family of curves representing a $B=0$ shot.

It can be shown algebraically that the depth range, Δ, is independent of the value and sign of the B factor, so that, for any transmission characteristic whatsoever, we may write

$$D_N - D_0 = \frac{NtK}{C} \qquad (8)$$

whence $$D_2 - D_0 = \frac{2tK}{C} \qquad (8a)$$

and $$D_1 - D_0 = \frac{tK}{C} \qquad (8b)$$

where D is expressed in ρ and K is the ρ constant, 6,000.

Finally, combining Eqs. (8a) and (8b), we may write

$$D_1 = \frac{D_2 + D_0}{2} \qquad (8c)$$

This furnishes us with the necessary relationships between all the significant distances in the scene. It remains only to show how D_1 determines the convergence or effective convergence of the camera axes.

If the camera axes are toed-in on a point at a certain distance, the film parallax, z_z, of this point will be zero. If, then, the images are projected on a screen with $z_{cL} = 0$, the point will appear on the plane of the screen, i.e. at N_1. Hence the original distance of the point was D_1. In other words, when $z_{cL} = 0$,

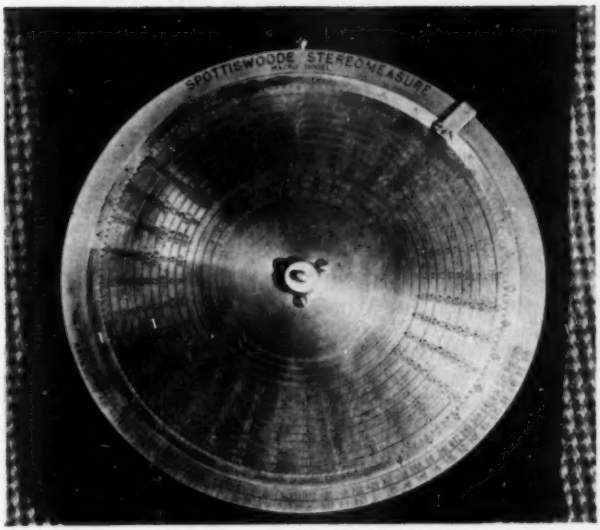

Fig. 4. Front side of the Stereomeasure (built in 1950), a calculator for relating D, Δ, M, f_c, t_c, cot φ and m_d for all shooting conditions likely to be encountered in the studio and on location.

the point on which the camera axes are converged is distant D_1 from the camera.

The half-angle of convergence being denoted by φ, it is evident that

$$\varphi = \tan^{-1} \frac{t_c D_1}{2K} \tag{9}$$

where t_c is in inches, and D_1 in ρ. In terms of d_1, the distance in inches from the camera to the point of convergence, we may write

$$\varphi = \tan^{-1} \frac{t_c}{2d_1} \tag{9a}$$

If, which is preferable, each optical system is laterally displaced inward through a distance, h, in relation to the film, we may write instead,

$$h = \frac{f_c t_c D_1}{2K} \tag{10}$$

Or, expressed in terms of d_1,

$$h = \frac{f_c t_c}{2d_1} \tag{10a}$$

We suggest that h (and its projection counterpart, H) be denoted by the term *edge-in* to differentiate it from physical convergence of camera and projector axes which is often conveniently described as *toe-in*.

The Stereomeasure

With the aid of the reciprocal distance system and Eq. (8) and its variants, an experienced stereotechnician can make all the necessary depth range and depth content calculations in his head, finally obtaining the values of φ or h from simple tables. However, as an aid to memory, these relationships and others have been embodied in a calculator, the Stereomeasure, which was designed and built in 1950 and has since been used for every one of our productions. One side of this calculator is shown in Fig. 4. It gives immediate numerical answers to all problems of how the camera should be set up to produce the effect in space de-

manded by the director, whether this be intended to soothe or startle, and whether the continuity from shot to shot be a matching or a deliberate mismatching of planes. Recently, with the aid of metric units and other simplifications, it has proved possible to design a much more compact version of the Stereomeasure which contains the same information but lends itself to quantity production.

So far we have been concerned with the space relationships obtaining between a scene existing in real space and the same scene as reconstructed in stereoscopic space by a binocular spectator sitting in the motion picture theater; and we have seen how these two quite different types of space can be related to one another by adopting new systems of measurement and comparison.

Stereoscopic Magnification

The next step is to examine how the size and shape of objects are affected by their stereoscopic transmission and reproduction. It is well known that a monocular image is essentially ambiguous, for the data it contains can (in the absence of other evidence) be construed by the spectator's mind as presenting a small object at a near distance or a much larger object farther away. By contrast, a binocular image — on the basis of the stereoscopic data it contains — is entirely unambiguous; it is determinate in size, shape and position. But these characteristics do not necessarily conform with those of the object represented; its image in space may be larger or smaller, widened or elongated, nearer or farther away. These distortions are certain to arise when presenting pictures on large screens; but whether they are objectionable or not depends on a great many factors, some stereoscopic, some extra-stereoscopic, and some psychological, which will vary greatly from one spectator to another. Nonetheless, it is important to be able to determine mathematically what distortions the image has undergone, and this must form an integral part of the whole transmission theory, just as much as an analysis of waveform distortion forms part of the theory of electronic amplification.

Considering the stereo image of an object in the real world, we may call the ratio of the stereoscopic image size to the real object size the *stereoscopic magnification*, which may of course be greater or less than unity. It can be shown that the depth of objects may undergo one type of magnification (called depth magnification, m_d), while the height and width of objects — dimensions between which a plano-stereoscopic transmission system does not discriminate — undergo another type of magnification, called width magnification, m_w.

Stereoscopic magnification varies, among other things, with the size and sign of the B factor. In the general case, in which $B \neq 0$, we may write, for any given plane in the image having a nearness factor, N,

$$m_d = \frac{Vt}{Mf_c t_e}\left(\frac{B}{Nt} + 1\right)^2 \qquad (11)$$

When $B = 0$, the expression in brackets equals unity, and the equation reduces to

$$m_d = \frac{Vt}{Mf_c t_e} = \frac{A}{C} \qquad (11a)$$

It can also be shown that, in the same general case in which $B \neq 0$, the width magnification for an image plane having a nearness factor, N, is given by

$$m_w = \frac{t}{t_e}\left(\frac{B}{Nt} + 1\right) \qquad (12)$$

When $B = 0$, this reduces to

$$m_w = \frac{t}{t_e} \qquad (12a)$$

Finally, since it is often the shape of objects which is more important to their acceptability than their absolute magnification along any dimension, it is helpful to introduce the concept of the *shape ratio*, μ. Then

$$\mu = \frac{m_d}{m_w} = \frac{V}{Mf_c}\left(\frac{B}{Nt} + 1\right) \quad (13)$$

Since Eqs. (11)–(13) involve the B factor, it is convenient to have an expression by which this factor can be easily reckoned when working out numerical examples. It is assumed that C and D_1 are known, as they will be when shooting conditions have been established. Then,

$$B = \frac{CD_1}{6{,}000} - t \quad (14)$$

where f_c, t_c and t are measured in inches, and D_1 in ρ. If d_1 (in in.) is employed in place of D_1, this expression becomes,

$$B = \frac{C}{d_1} - t \quad (14a)$$

The Orthostereoscopic Condition

This is the condition of perfect image reproduction — i.e. that in which the image as a whole is geometrically congruent with the scene it represents. So many inventors have claimed a system which produces a distortion-free image that it is worth investigating just what orthostereoscopy entails. For linear reproduction it is necessary to have $B = 0$, and for geometrical congruence $m_d = m_w = 1$, so that $\mu = 1$. Substituting $m_w = 1$ in Eq. (12a), we have $t_c = t$. Putting $t_c = t$ and $m_d = 1$ in Eq. (11a), we have $V = Mf_c$. Thus the three conditions for geometrical congruence are:

$$\left.\begin{aligned} B &= 0 \\ t_c &= t \\ V &= Mf_c \end{aligned}\right\} \quad (15)$$

If the focal length of the camera lens and the screen size have been determined, the spectator's viewing distance is fixed. Furthermore, for a normal space film having a depth content of Δ_2, it can be shown that, under orthostereoscopic conditions,

$$D_2 = \frac{12{,}000}{Mf_c} \text{ rhos} \quad (16)$$

when the rear of the scene is at D_0.

For example, if $M = 300$ (i.e. a 20 ft 8 in. screen), and if $f_c = 2$ in., the nearest object to the camera must not be closer than 20ρ, i.e. 25 ft. Thus no shooting system can claim to eliminate distortion which does not comply with all the conditions of Eq. (15); and no system which complies with these conditions can claim to be practical for commercial films, since it would be limited to the taking of long shots. Hence it may safely be asserted (notwithstanding many statements to the contrary), that distortions are inseparable from stereo films — as indeed they are from flat films — and that it is therefore necessary to study their character and incidence.

In Part II of this paper are to be found numerical examples which demonstrate very clearly the type of distortion to which a stereoscopic system is prone, especially when large B values are employed. It is the depth of objects which tends to be most exaggerated, because of the squared term in Eq. (11); as the scene recedes, so it rapidly becomes more elongated. Experience confirms the ill effect caused by very large values of B, but it would appear that objects in the foreground and middle distance are the worst sufferers, perhaps because the eyes normally look downward on them more than on distant objects, so that one is more often reminded of their shape.

Binocular Magnification

There is however another kind of magnification to which the stereoscopic image is subject. Stereoscopic depth magnification is based on the supposition of a slight depth shift, dp, in the object position, which is then compared with the corresponding shift in the image position, dP. In other words,

$$m_d = \frac{dP}{dp},$$

a concept which corresponds to that of a one-eyed spectator with a foot-rule at the camera and in the theater — although, of course, in the theater he would

need two eyes in order to construct the depth image at all. Now if a two-eyed observer were stationed at the camera position, the front plane of a given object in the scene would subtend some angle, ω, at his two eyes, and the back plane of the same object a smaller angle, ω'. If $\omega - \omega'$ were not too small an angle for the eyes to discriminate, the object would appear stereoscopically solid. Now suppose this object to be imaged and transmitted to a theater under given conditions. For a spectator of known position and characteristics, the same object will subtend at its front plane an angle Ω, and at its rear plane an angle, Ω'. The ratio of a small change in the image angle, Ω, to a small change in the object angle, ω, may be called the *binocular magnification*, m_b, and an expression may be found for it which is analogous to those enunciated above in Eqs. (11) and (12).

$$m_b = \frac{d\Omega}{d\omega} = \frac{C}{A} = \frac{Mf_e t_e}{Vt} \qquad (17)$$

Note that m_b is purely a form of depth magnification, having no relation to the width of the image, that it is independent of the value of B, and that (were the two kinds of magnification found to be multiplicative in effect), when $B = 0$, $m_d = 1/m_b$. Their inverse operation has important practical consequences which will be discussed in Part II.

The Complete Theory

This short outline of fundamental principles can of course be developed very much further, and its fuller implications are set out in the work already cited.[4] These shed light on fascinating possibilities of set design which take advantage of the image distortions we have noted, just as the set designer of today makes fullest use of the potentialities of linear perspective. They help to analyze many new techniques in cell and puppet animation. They enable the camera designer to lay down parameters for the construction of professional stereo film cameras. They enable a producer to undertake a complicated studio picture in the confidence that all the problems along the way — titles, optical effects, back projection, stereo windows, and so on — can be surmounted with a full knowledge of what is being done.

PART II: PRACTICE

It may be that a transmission theory such as this, containing as it must many new terms and concepts, will at first seem difficult to grasp, and perhaps too abstract for the practical needs of film makers. Yet just these objections were made when sensitometry was first introduced as a science. It was puzzling to have to think of densities and gammas and toe exposures when a mere twist of a lens diaphragm had previously seemed to suffice; yet today all these and many other terms are so much a matter of instinct that they trip off the technician's tongue with scarcely a second thought. The practice and nomenclature evolved here for the 3-D film have been carefully worked out with the needs of the professional film maker in mind. Very soon he is just as happy with depth ranges and nearness factors as he is with the rest of the science of film, because he can see what these things mean as soon as he starts to make his first stereoscopic movie.

Within the limits of this part of the paper, we shall try to make the reader feel that he is sharing in the production of a section of *The Black Swan*, one of the many films now completed in accordance with this technique. We shall show how the stereoscopic constants are computed, how film parallax is afterwards determined, how camera errors, if present, may be corrected, and how the image in space finally appears to a member of the audience.

The camera on which this film was to be shot consists of the twin assembly de-

Fig. 5. 3-D camera mounted on crane during filming of *The Black Swan*.

picted in Figs. 5 and 6, this being the only equipment presently available in England for double-band 35mm shooting. As can be seen from the nearer view (Fig. 6), two Newman-Sinclair cameras are mounted on a stereoscopic base, shooting into mirrors set at 90° to one another, and having their apex facing the scene.[8] This arrangement provides for convergence by physically toeing the cameras inward, and it enables t_e to be varied from a maximum of 8 in. to a minimum of 1.25 in. (2.5 in. with the 35-mm lenses). To set against this usefully wide variation, the camera has manifold disadvantages, chief of which are that a nonstandard image geometry results from reversal at the mirror surfaces, and that inaccuracies of setting due to faulty construction are so serious and unpredictable that a special optical printing technique has had to be devised to correct them.

The first of the two shots we are going to consider in detail depicts the Male Variation danced by John Field. He finishes with a held pose which, in the stage version of the ballet, enables the audience to applaud. As a counterpart to this, the director, Len Reeve, proposed a stereoscopic curtain effect, making use of a pair of decorative banners which were to be raised before the scene at the end of the first shot, quite close to the audience's eyes. The immediate cut to the next shot would reveal a similar pair of banners at a slightly greater distance, hiding the scene; and as these were raised out of sight, another pair behind them would be revealed, only to rise in favor of a third, and so on until Beryl Grey was discovered at the back of the set beginning her variation.

Always when making a 3-D film the director will search for visual material which will enhance the sense of forward

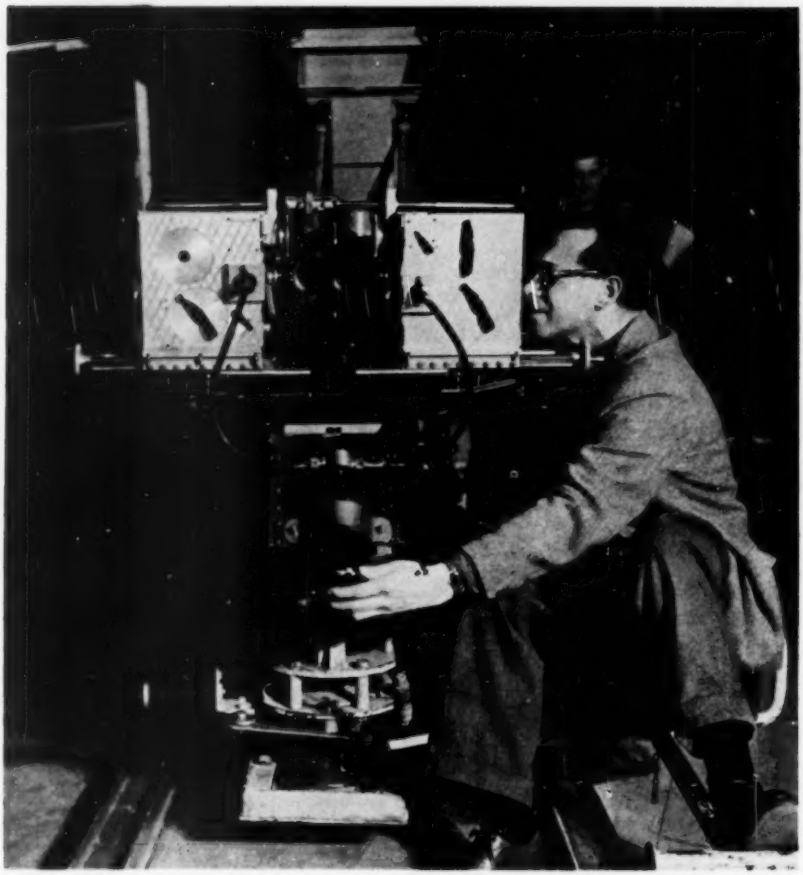

Fig. 6. Front view of 3-D camera showing Newman-Sinclair units in opposed positions and 90° mirrors. Matched lens pairs are available in the normal range from 35mm to 100mm, with coupled focusing; a centrally mounted Mitchell-type viewfinder is used for monitoring.

and backward movement, of nearer and farther away. In unskilled hands this may easily degenerate into a trick, a mere device for showing off the third dimension to the best advantage. But the imaginative director will find that all kinds of new visual ideas will present themselves, which would be ineffective in the ordinary flat film, or which take on a new vitality in the more real world of 3-D. The transition we are discussing proved very successful because the totally unexpected appearance of the banners caused the audience's attention to move rapidly into the extreme foreground, this being followed by the smooth withdrawal of attention to the back of the next scene, the time occupied being sufficient to

Fig. 7. Slate 15 of *The Black Swan*. Camera out of picture on left, banners raised successively in pairs to reveal Beryl Grey in background.

cover the musical transition and hide the break which was intended for stage applause.

Computing the Stereo Settings

The simple mechanics of this shot are shown in Fig. 7. But how is the stereo-technician on the set to ensure that the director's wishes as to the placing of the scene in space in the ultimate movie theater are precisely carried out? First it is necessary to decide the size of screen for which the film is to be shot, since this will determine M, the one element in the C factor which is not controllable when shooting. If the anticipated variation of screen width is not very great, it is best to set M for the largest screen size, and accept some loss of depth on smaller screens. But if a wide range of screen sizes must be provided for, it is better to find a mean magnification so that the loss on the smallest screen is not too great, while accepting some divergence on infinity points on the large screens unless these are corrected in an optical printing

stage.* *The Black Swan* was to be presented for 22 weeks on a screen only 10 ft 4 in. in width ($M = 150$), and this suggested shooting it for a 15-ft screen ($M = 218$), since it was known that results on even a 20-ft screen would then be entirely acceptable.

Accordingly, the Stereomeasure was permanently set at $M = 218$, this being analogous to the choice of a film emulsion for a production, which gives rise to a fixed speed setting on the exposure meter. While the movement of the camera on its crane was being rehearsed, distance measurements were taken from it to the dancer and to different parts of the set. These measurements were made with the special Stereotape graduated in ρ on one side and linear units (for focusing) on the other.

For the first shot, the entry in the stereotechnician's log begins as follows:

> *Slate 35:* LS Prince (John Field), who dances his Variation. Rear of set at 10ρ. During the dance, camera tracks in, and the Prince finishes in MLS at 33ρ. At end of dance, as Prince kneels, banners rise in front of him, covering whole frame, at 65ρ from camera. For continuity with following shot (already taken), banners should be at or around $N_{2.75}$.

It should first be determined whether this shot can be made with $B = 0$, i.e. with linear transmission, placing D_0 at 0ρ. Since the banners are to appear at $N_{2.75}$, the depth range is $\Delta_{2.75}$. The cameraman having selected a 35mm lens ($f_c = 1.38$ in.), it can readily be determined by Eq. (8), or from the Stereomeasure, that $t_c = 2.1$ in. However, this value of t_c is not obtainable on our camera with the 35mm lens, and the shot must therefore be recalculated for $B+$. The simplest procedure is as follows.

Taking the minimum setting of t_c (i.e. 2.5 in.), we then have M, f_c and t_c, and therefore the C factor. The most distant plane in the set, 10ρ (i.e. 50 ft), is set at infinity, D_0. The Stereomeasure, solving Eq. (8) directly, gives 30ρ as the value of D_1, and shows that the banners will in fact appear at $N_{2.75}$.

Hence the stereotechnician's entry concludes,

> Treat shot as $B+$, with $f_c = 35$mm, $t_c = 2.5$ in., and cot $\varphi = 160$. D_1 to be at 30ρ. Nearness factor of raised banners works out at $N_{2.75}$, as desired.

These measurements and calculator readings occupy only a couple of minutes, and in a few moments more the camera is set to $t_c = 2.5$ in. and cot $\varphi = 160$, the latter value having been obtained from scales on the Stereomeasure which relate t_c and D_1, as in Eq. (9).

Two further points deserve comment. Firstly, what could have been done if the proposed settings had placed the banners in the wrong plane in theater space? Had they proved too far away, it would have been possible (a) to reduce the distance in the studio between camera and banners, (b) to increase f_c, or (c) to increase t_c. Both (a) and (b) alter the composition of the shot, and so (c) is usually the preferable alternative. Had the banners proved to have too great a nearness factor, it would have been necessary to resort to the inverse procedure of (a) or (b), since the t_c setting was already a minimum; This points to the need of incorporating the lowest practicable minimum t_c in the design of the camera.

Secondly, it may be asked what effect on the appearance of the shot is likely to result from changing $B = 0$ to $B+$. Setting the rearmost plane at D_0 should of course place it at infinity, and clever set design will in fact produce a very

* The excessive positive z_s resulting from projection with too large a value of M can be corrected by supplying a negative correction of suitable size which will alter B and increase the N value of the nearest planes. This can be done by projecting with z_{CL} negative, but better by optical correction. Note that N factors will be increased *both* by the larger M and by the extra negative screen parallax.

marked elongation, an advantage when designing spectacular scenes. The backgrounds of normal interior sets are not likely, however, to suffer any appreciable deformation. It is the foregrounds, especially when they contain objects of familiar shape, which may be more visibly distorted. An example of a visible kind of stereo distortion is worked out from the data on the following shot. Practice, and frequent viewing of 3-D films, will tell the stereotechnician what is acceptable and what is not. It is unlikely, however, that he will satisfy everyone; for reasons that are not yet clear, people differ enormously in their sensitivity to stereoscopic shape and size.

When the stereo settings have been made, one more step is required to be taken before the camera is ready to roll. This is the Stereotest, which provides the necessary data under the microscope to determine the actual, as contrasted with the nominal, values of cot φ (or h) and t_e. To make this test, a small target board resembling a ping-pong bat is run out first to a distance of 40ρ and then to 22ρ with the aid of the Stereotape, a few frames of film being exposed at each distance. The lens focus is set at 15 ft for both shots, since the lens-to-film distance enters into the equations, and must therefore remain constant.

The shot which follows Slate 35 in the film had already been taken. It was the nearness of its front banner which had to be exceeded in 35, in order to produce the desired progression in space. The entry in the stereocontinuity book is as follows:

> *Slate 15:* Shot opens with pair of banners in CS, filling screen, at 79ρ (6 ft 4 in.). Banners raised out of picture to reveal further pair, and so on, till raising of 4th pair reveals Odile (Beryl Grey) in LS, who starts to dance her Variation. Camera static, rear of set at 13ρ (39 ft). At end of slate, Odile has danced into MS at 48ρ (10 ft 5 in.).
>
> Treat shot as $B+$, with $f_e = 50$ mm, $t_e = 1.25$ in. and cot $\varphi = 220$. Thus $D_0 = 13\rho$, $D_1 = 44\rho$, and $D_2 = 75\rho$, since $\Delta_1 = 31\rho$. Hence front banner is slightly closer than N_2, actually $N_{2.12}$.

The method of working out this shot need not be repeated here, since it resembles the previous example and can be checked with the help of the equations already given. Although the stereotechnician will seldom have to force the cameraman's hand in the choice of lenses, or the director's in the arrangement of a scene, he is nevertheless bound to be constantly preoccupied with the smallest value of t_e which his equipment will provide. In studio work, with its large depth ranges, he is likely to be pressing against this limit much of the time. In Slate 15, for example, 1.25 in. was the absolute minimum t_e available with the 50-mm lens, and had it been desired to hold the nearest banner farther away than $N_{2.1}$, while retaining it at the same field size, nothing could have been done — except by allowing divergence to occur in the farthest planes of the shot.

Image Distortion in the Theater

The data already provided for Slate 15 makes another interesting analysis possible; by studying the shape of different parts of the image, it is possible to get a clearer idea of the distortions set up in the motion picture theater. Let us consider the plane in the image corresponding to Beryl Grey's position when she has danced forward at the end of the shot, and is at 48ρ. The spectator is assumed to be at a distance from the screen of $2.5W$.

> *Example:* It is required to find the depth magnification, width magnification and shape ratio for Slate 15 at a plane in the scene distant 48ρ from the camera, when the spectator is seated at $2.5W$ from the screen for which the film was shot.

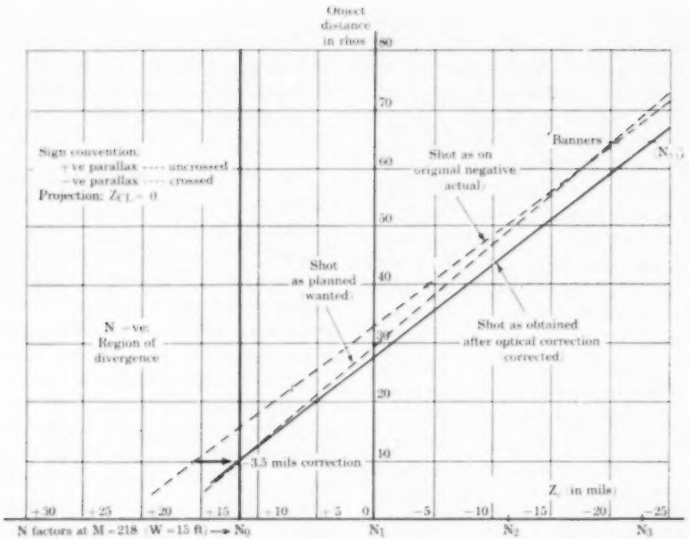

Fig. 8. Graphical analysis of Slate 35 of *The Black Swan*, showing relation between object distances in scene and nearness factors in cinema, together with method of postcorrection of convergence errors by optical printing.

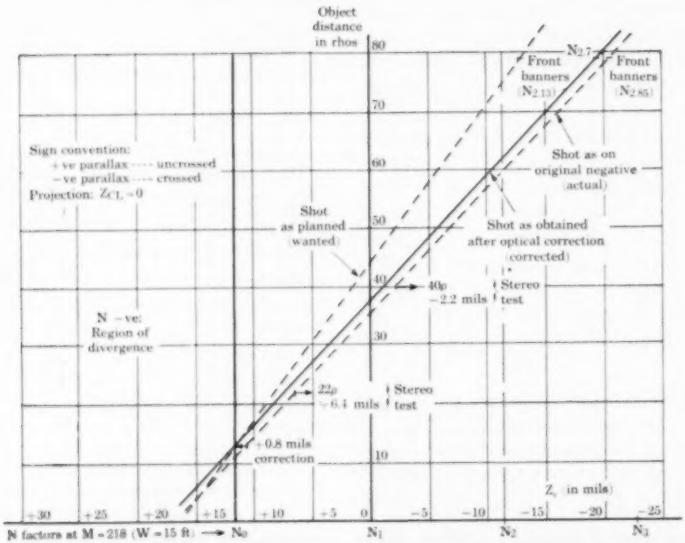

Fig. 9. Graphical analysis of Slate 15 of *The Black Swan*, as Fig. 8, but showing also how the Stereotest readings are plotted to give the depth relationships on the camera negative.

Data: $M = 218$, $\therefore W = 15$ ft, and $2.5W = 450$ in., $\therefore A = 1{,}125$ sq in.

$D_1 = 44\rho$, $\therefore 48\rho = N_{1\text{-}\infty}$.

$f_c = 50$ mm $= 1.97$ in., $t_c = 1.25$ in., $\therefore C = 536.9$ sq in.

From Eq. (14),

$$B = \frac{536.9 \times 44}{6{,}000} - 2.5$$

$$= 1.44 \text{ in.}$$

$$\left(\frac{B}{Nt} + 1\right) = 1.53$$

$$\left(\frac{B}{Nt} + 1\right)^2 = 2.34$$

Hence, from Eqs. (11), (12) and (13),

$$m_d = 2.10 \times 2.34 = 4.9$$
$$m_w = 2.00 \times 1.53 = 3.1$$
$$\mu = 4.9/3.1 = 1.6$$

From this it is safe to conclude, and can indeed be observed in the film, that some elongation of the side of the face and the shoulders will be noticeable, especially if the dancer turns so that the same features undergo differing magnification in quick succession. The more interesting case in which the dancer pirouettes with outstretched arms would call for integration, since the depth occupied by the arm stretching toward the camera would be nonlinearly magnified in a $B+$ system. This difficulty can be overcome by employing an extension of the technique next to be described.

Interpreting the Stereotest

A graphical presentation, based on the principle of Fig. 3, greatly simplifies the study of scenes in space. So long as the distance of a plane in the scene from the camera is known, its position in space in the theater can be read off in an instant, together with the parallax which a point in this plane has produced on the camera negative, and finally the convergence and interaxial separation which obtained when the scene was shot. Figures 8 and 9 are the representation of Slates 35 and 15 respectively in *The Black Swan*. After development, synchronized left- and right-eye frames of the two Stereotests are cut from the negative tracks and placed under a special Swift traveling microscope with pilot-pin registration. By placing the two frames successively on the same pins, the parallax between corresponding points on the tests, at each distance, can be read off with great accuracy. These results from the actual film may be tabulated as in Table IV.

Table IV

	z_c (mils)	
	40ρ	22ρ
Slate 35	−4.3	+7.2
Slate 15	−2.2	+6.4

It should be emphasized that, because of the extremely small parallaxes needed to produce a δN of only 0.1 (see Table III), the most painstaking efforts must be made to keep microscope reading errors down to the lowest possible limits. Figures 8 and 9 show how the 40 and 22 ρ points are plotted on a graph which represents z_c on the x-axis and distances in ρ on the y-axis. Since, on such a graph, $B = 0$, $B+$ and $B-$ systems are equally represented by straight lines, it is only necessary to lay a ruler between the 40ρ and the 22ρ points. The resulting line represents all the stereoscopic relationships in the negative, and the x-axis can of course be additionally graduated in N values for any assumed value of M by using the relationship,

$$N = 1 - \frac{Mz_c}{t} \qquad (11)$$

In Figs. 8 and 9 this has been done for $M = 218$, the magnification for which the film was shot.

With the aid of a special protractor (not shown in the diagrams), it is possible to read off with great accuracy the actual values of t_c and φ (or h) which obtained when shooting. These results may be tabulated as in Table V.

No practical technique is imaginable for changing the magnitude of the C factor after shooting (assuming that M re-

Table V

	cot φ		t_e (in in.)	
	Wanted	Actual	Wanted	Actual
Slate 35	160	145	2.5	2.72
Slate 15	220	234	1.25	1.42

mains fixed), and therefore the slight error in t_e will result in any given span of distances in the scene occupying a somewhat greater span of nearness factors in the cinema than the stereotechnician intended. On the other hand, errors in the B factor resulting from inaccurate convergence can be perfectly corrected in an optical printing stage. This is because convergence is essentially no more than the sideways displacement of the films relative to the images formed on them by the lenses, a fact which is easy to recognize in the case of h, but which applies also to φ. The method of correction will be apparent from Figs. 8 and 9. We know from the entries in the stereocontinuity log the ρ distances which were supposed to correspond with D_0 and D_1 (i.e. N_0 and N_1 in the theater); in Slate 35, $D_0 = 10\rho$, and $D_1 = 30\rho$; in Slate 15, $D_0 = 13\rho$ and $D_1 = 44\rho$. These pairs of points enable us to plot the "Wanted" curves for these shots. Figure 8 shows that the N_0 (D_0) line cuts the "Wanted" curve at 10ρ, but the "Actual" curve at 15ρ, thus indicating that an increasing amount of divergence will be introduced at $M = 218$ for scene distances greater than 15ρ. Figure 8 also shows that by displacing the "Actual" curve sideways and in the increasing negative direction through 3.5 mils (as measured on the x-axis), N_0 will be reestablished at 10ρ, thus producing the "Corrected" curve. This is equivalent to giving the image a lateral displacement in relation to the perforations of -3.5 mils, and this figure is accordingly entered in the correction table for the film. The reason why the "Corrected" curve still differs from the "Wanted" curve is, as explained above, that t_e is slightly greater than it should be. This decreases the gradient of the curve, and thus amplifies the change in N values for any given range of object distances.

A correction of 3.5 mils corresponds to a change of nearness factor (δN) of 0.3 at $M = 218$. Corrections with this particular camera tend, however, to run much higher, averaging about 10 mils and sometimes exceeding 25 mils ($\delta N = 2.2$ at $M = 218$). This would mean that an object at infinity would be represented stereoscopically as halfway from the screen to the spectator, or vice versa — an error which would, of course, completely destroy the 3-D effect of the scene. With screens of larger size than 15 ft, the error would be even greater.

The result of the correction to Slate 35 is that D_0 is now correctly placed at N_0 when projected with $M = 218$. Had there been no error in t_e, all other points in the scene would also have been correctly placed. As it is, the banners at the end of the shot project in the theater at $N_{3.1}$ instead of at $N_{2.75}$ as planned.

The analysis of Slate 15 (Fig. 9) is carried out in exactly the same way, and here the correction is found to be $+0.8$ mils, the smallest ever encountered, the plane of D_0 having been moved back merely from 13ρ to 11.5ρ.

When better camera equipment is available, correction of every shot in this way will not of course be necessary. The technique of the stereotest will, however, continue to be useful as a laboratory check on the accuracy of the very precise camera adjustments required — much as the routine D-log E curve provides a daily or hourly check on film processing. But this by no means exhausts the possibilities of graphical analysis and optical stereo correction. For instance, when the layout of a set design is available, it becomes possible to study the mechanics of a complicated 3-D shot long before the film reaches the studio. Planes in space can be accurately charted, the necessary camera constants determined, and if the shot proves impossible, alterations can

be made in the set before rather than after construction takes place. Again, when the public learns how to look at quick-cutting sequences in 3-D, it will often be possible to build these up out of material shot with an ordinary "flat" camera, giving each shot a single plane in space by means of optical printing, and varying this plane if necessary by means of optical zooms. The construction of such a sequence is greatly simplified if it can be plotted in space, with the optical corrections read off from the graphs. The same technique may be applied during the editing stage of an ordinary 3-D film to readjust a shot which does not fit into the space continuity finally decided on. And lastly, optical printing may be used to match infinity points (or any other points) in converting films to use on very large or very small screens.

Since optical printing is necessary with our camera to provide left-to-right image reversal, the transfer from original negative to master positive is made use of also for the stereo correction and for the introduction of the necessary optical effects. Duping and printing then become normal contact processes. There are of course limits to the width of the stereo correction which can be printed on a single film without trespassing too close to the final projector aperture. If the correction is too large, it must be split between the two bands of film. However, the larger the screen for which the film is shot, the smaller the absolute magnitude of the corrections. Furthermore, an additional width is provided for the corrections on each film by the printed-on stereo window.

The Stereo Window

This is the last printing stage to which the film must be submitted. *The Black Swan* has a fixed stereo window at approximately N_2 (with $M = 218$), containing patented fusible components along its top and bottom edges, so that these contribute to the stereoscopic effect nearly as much as do the vertical sides. The window also could be incorporated at the master positive stage, but extremely high contrast is necessary in a traveling matte to avoid fogging the image, and it is therefore best printed on at the release print stage.

The stereo window is an essential component of most 3-D films, and its existence and position in space must be contemplated from the beginning. More than half of the shots in *The Black Swan* were designed to occupy the full stereoscopic space between N_0 and N_2 (i.e. $^{\Delta}N_2$); but as the scene was a ballet stage with dancers on it, effective space would have been seriously telescoped had not a forward window permitted a free movement of the image out to a distance halfway between the screen and the spectator.

Appearance of the Scene in the Theater

It is now time to stand back from the technicalities of production and ask how the two shots we have so often referred to appear to the ordinary audience in the movie theater. In the first place, whether they are conscious of it or not, spectators will see the entire scene framed behind the forward window, with the exception of one or two self-supporting objects such as the banners in Slate 35 and Beryl Grey's arms and back-bent body in several shots. Since the screen, if free from blemishes, becomes invisible in a 3-D film, the window is easily mistaken for it. Thus an audience might be led to comment on *The Black Swan*, "Practically nothing comes out in front of the screen," although, in point of fact, almost half the film does so. But the actual — even if unrecognized — use of theater space has one extremely important advantage which we have often heard commented on during commercial presentations of the films. Because of the increase of stereoscopic depth magnification (m_d) with distance from the screen, the spectator in the most distant balcony seat has a view of the film which is just as dramatically effective as that ob-

tained by a person sitting comparatively close to the screen.

In a stereocinema, distortions are usually least at a seating distance of 2 to 2.5W, and if — but only if — the picture has been shot so as to be acceptable from this position, it will not as a rule appear unnaturally elongated even if viewed from much farther away. This is due to the inverse effects of m_h and m_w described under the heading "Binocular Magnification," earlier in this paper. Practical viewing experience reveals a substantial constancy in the depth-appearance of the image between the front and back seats of any normal theater; but this will only be true if N values of 2 or more are employed continuously, for otherwise the distant spectator will become conscious of the gap existing between himself and the screen. In our experience, provided that a sufficiently high level of technical perfection is achieved in the production and projection of a 3-D film, nearness values as high as N_2 can be held continuously (for example, in a stereo window), with much larger values for the normal duration of an especially dramatic scene.

Granted, then, that the scene in *The Black Swan* will be framed in an N_2 window; and that the audience, though for the most part unconscious of this fact, will be aware of seeing a picture totally different from the normal one, and different too from a stereo film presented wholly behind the plane of the screen. Granted this, what else will the audience be aware of? In the first place, the fact that their eyes can now scan the scene in depth means that the visual content of each shot will be much increased, and this in turn necessitates holding the shot longer on the screen. Today, when few audiences have seen 3-D films before, quick cutting is ineffective, since each shot takes an appreciable time to establish itself, after which its quick disappearance produces an effect of disappointment and even annoyance. This is an extension of the principle on which color films tend to be cut somewhat slower than black-and-white ones. Secondly, the audience will be much more aware of the importance of depth relationships in a scene. Figure 10 shows a shot in *The Black Swan* which is of a type particularly impressive in 3-D. Whereas in a flat film it would achieve no more than the normal effects of deep focus, the third dimension gives the foreground figure an almost physical effect of size and massiveness. Even when the spectator is consciously watching the White Swan trying to make her presence noticed, he feels his eyes drawn to the menacing figure of the Enchanter standing much closer in the foreground and trying to banish her away.

In the third place, the audience almost completely loses the impression that it is watching the photographic rendering of a scene. Actual reality seems to lie before it, and when the film is in color this reality is almost complete.

Thus in the first scene we have been considering, the Male Variation danced by John Field will appear almost as if one were present in the theater. The raising of the banners right in front of the eyes produces by contrast a momentary feeling of complete surprise; and after a brief pause, the successive lifting of four pairs of banners out of scene — flowing in the same unbroken rhythm — disguises the fact that the scene has changed and thus introduces an element of fantasy when both a new decor and a different dancer are revealed.

Part III: A Critique of Existing Procedures

It may well be asked how, in the absence of a general transmission theory, proper camera and projection conditions could have been set up for the stereoscopic films produced up to now and those in current production by other

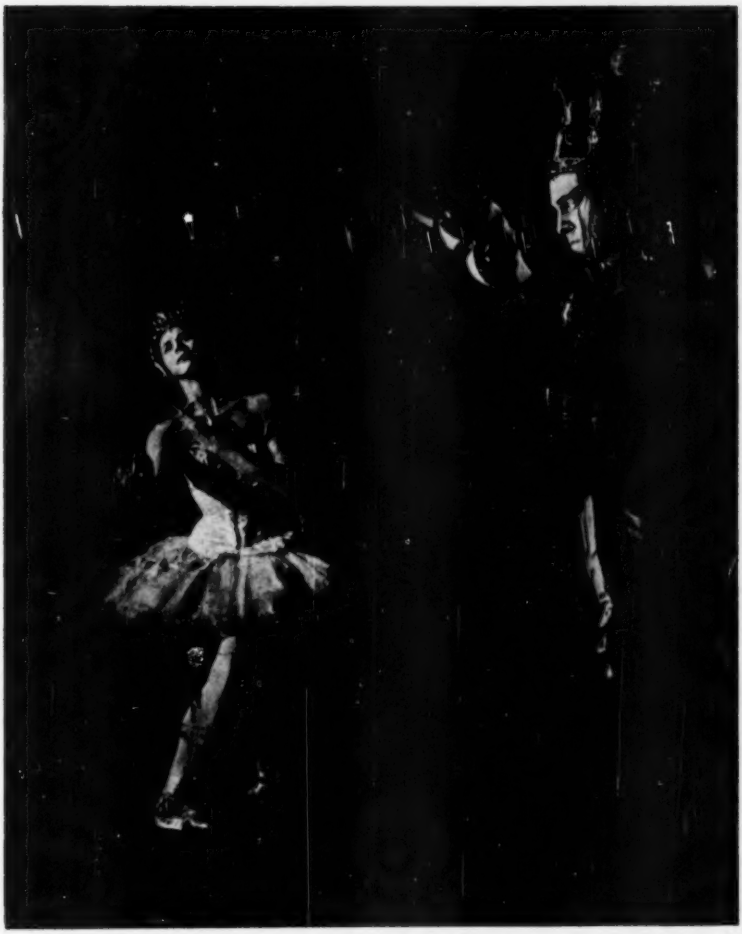

Fig. 10. The third dimension in this type of shot gives the foreground figure an almost physical effect of size and massiveness.

groups. The answer is threefold. First, the basis of an accurate theory was laid just prior to the war by Professor J. T. Rule,[8] and was apparently used by J. A. Norling in the production of his well-known and very successful films. Second, a number of pictures have been produced outside the United States on the basis of no proper transmission theory at all, severe eyestrain having been avoided only because the size of the projection screen was very small. Third, and most recently, the early work of Rule has been overlooked or ignored, and a number of simplified procedures have been suggested, many of them the subject of exaggerated claims, such as that they completely eliminate distortion, or that they make 3-D filming

conform to the procedures of the flat film, yet without loss of effect.

In this Part we shall discuss in some detail, using the method of analysis already derived from the general theory, two typical proposals, both in current use and both claimed to provide a perfect solution to all problems of stereoscopic transmission. The first makes use of a fixed interaxial separation of the camera lenses, and a variable convergence; in the second the convergence is fixed, but the interaxial separation is made variable.

Viewing of Real Objects and Stereo Images

It has been suggested — notably by Dewhurst[9] in Great Britain and more recently by an influential group in the U.S. — that the problem of 3-D filming is very simple: all that is necessary is to provide a fixed lens separation (t_e) approximating that of the human eyes and then converge the optical systems on some appropriate plane in the scene — this plane appearing, of course, in the plane of the screen when the film is projected with $z_{CL} = 0$. It has been further suggested that the convergence control ought to be coupled to the lens-focusing mechanism in such a way that D_1 is always the distance to the plane of sharpest focus. Thus, following focus would automatically alter the convergence, and (since t_e is already fixed) no special stereoscopic adjustments of any kind would require to be made. This, it is held, would reproduce the conditions of natural vision, and would provide strain-free viewing of the image by all spectators.*

* The same idea has recently occurred to the first producer of 3-D motion pictures in Hungary, M. Felix Bodrossy. "The Hungarian method," he writes, "solves the problem simply and radically: it starts off from the way the eyes work, and imitates nature. The eyes always focus automatically and at the same time converge on the object they look at. Our cameras do the same thing."[10]

The parallel with the human eyes is simple and attractive; but, from what has been said above, it will be apparent that the viewing of a stereoscopic image cannot at present be made to resemble human vision at all closely. The image in space is not even an optical image; it is a mental construction from data supplied solely by overlapped images on a flat screen. This construction is accomplished by methods not used in normal vision; for example, the spectator's eyes must remain focused at the screen distance, but they will be varyingly converged according to the distance of the point of attention, which may be much nearer or much more remote. Furthermore, in the real world, sense-data remain more or less constant when spectator and scene are fixed; but stereoscopic data may be made to vary widely according to projection conditions, and indeed cannot be kept constant when the size of the screen is changed. It is therefore not to be expected that a mere reproduction at the camera of the human eye separation — in the absence of human viewing methods — will of itself produce strain-free viewing. This cannot be so simply achieved until it becomes possible to create real or virtual 3-D images in space.

Limitations of Fixed-t_e Systems

Meanwhile, stereo camera systems which make use of a fixed "human" lens separation of 2.5 in. must be treated as having an awkward limitation common to all fixed lens systems designed to film pictures for large screens. The transmission system obtaining with a fixed value of t_e can be very clearly exhibited on a graph similar to Figs. 8 and 9. Reference to the section "Depth Range in the Scene," earlier in this paper, will show that the slope of the transmission lines is a function of the C factor (i.e. Mf_e/t_e) and t; and therefore, if M is assumed fixed for the film, t_e is fixed on principle, and f_e represents the focal length of the lens in use, all possible trans-

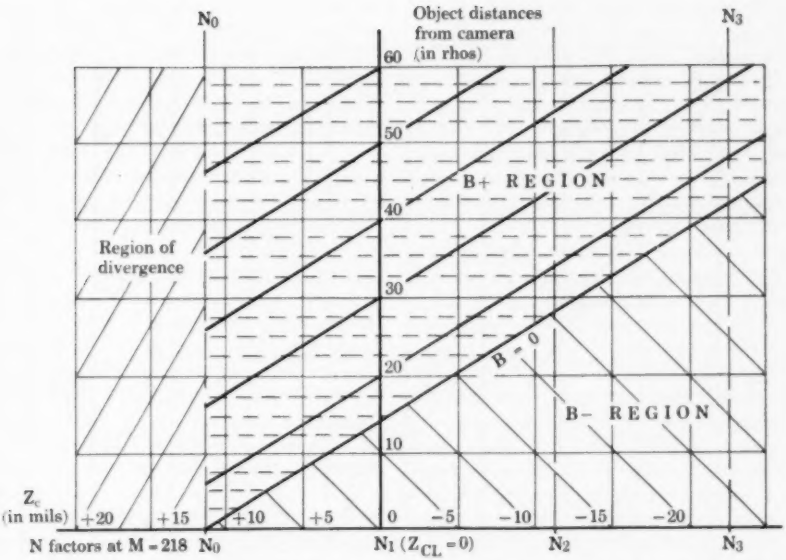

Fig. 11. Graphical analysis of "human vision" technique (i.e., t_c fixed at 2.5 in.). For $M = 218$, $f_c = 50$mm, all depth range possibilities are comprised in a series of parallel lines, such as those shown at 10ρ intervals, in the horizontally shaded region bounded by $B = 0$. For ρ values > 60 (distances < 8 ft 4 in.), extend the graph upward; for $N > 3$, extend it to the right. For $f_c > 50$mm, the parallel lines slope proportionately less steeply, and the depth range decreases; for $f_c < 50$mm, these lines slope more steeply, and the depth range increases. For $M > 218$, the region of divergence extends to the right, the intervals N_0, N_1, N_2 . . . becoming proportionately smaller, N_1 remaining at $z_c = 0$.

mission lines on the graph will have the same slope, and must therefore run parallel to one another.*

Figure 11 displays all the possibilities of such a transmission system, assuming $t_c = 2.5$ in., and taking $M = 218$ and $f_c = 50$ mm (i.e. 1.97 in.), so as to enable a direct comparison to be made with the shooting of Slate 15 of *The Black Swan*.

Then, from Eq. (8b),

$$D_1 - D_0 = \frac{2.5 \times 6{,}000}{218 \times 1.97 \times 2.5} \text{ rhos} = 13.97 \text{ rhos}.$$

This enables us to draw the $B=0$ line in Fig. 11, which also shows representative transmission lines drawn in at arbitrary intervals of 10ρ. The area under the $B=0$ line represents the $B-$ type of transmission, which gives rise to cardboarding and is therefore almost always undesirable; hence the camera convergence must never be set to give D_1 less than 13.97ρ (i.e. d_1 more than 35 ft 9 in.). When the lenses are focused at infinity, they must not, as might be expected, be aligned with their axes parallel; alternatively, if the lens and convergence mechanisms are coupled, the lenses must

* When the focus and convergence are coupled, this statement is not strictly true, for f_c is properly the lens-to-film distance, which increases slightly as the lens is focused nearer. Hence, as D_1 is brought nearer to the camera, the C factor will increase slightly and the depth range will be correspondingly reduced. This is a second-order error, which is ignored in Fig. 11.

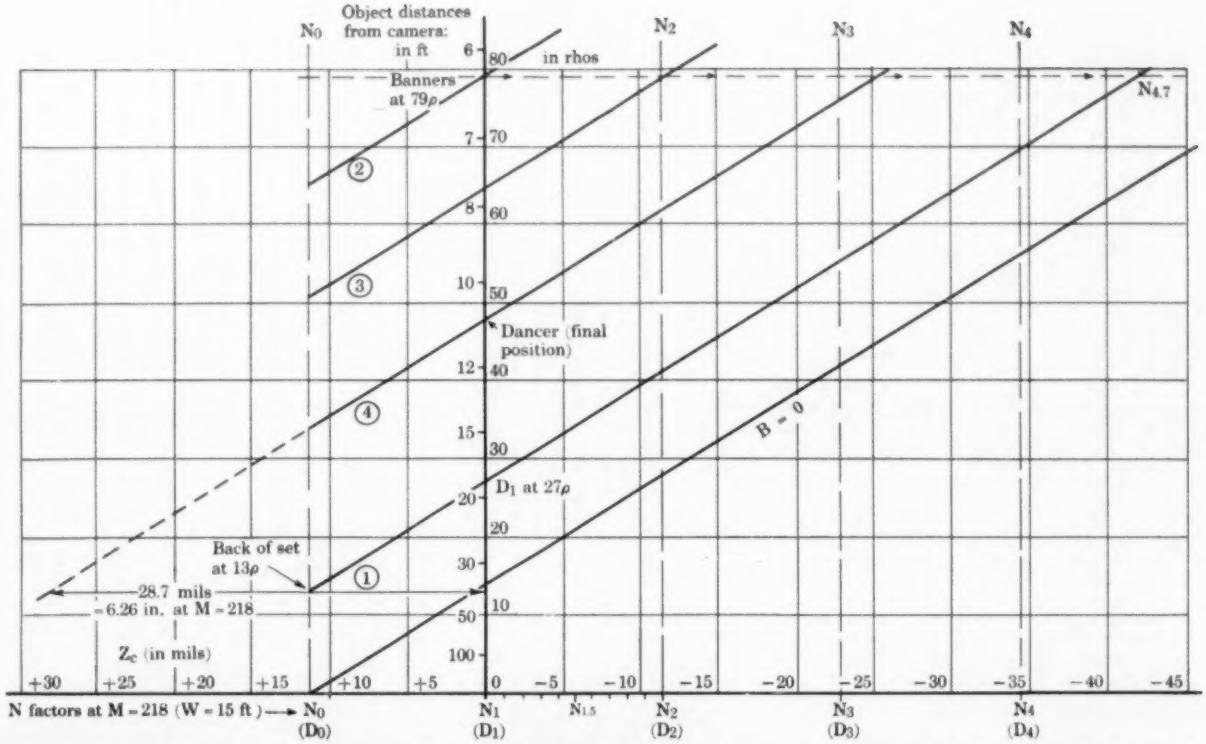
Object distances from camera: in ft
in rhos
N0
N2
N3
N4
N4.7
Banners at 79ρ
Dancer (final position)
D1 at 27ρ
B = 0
Back of set at 13ρ
28.7 mils = 6.26 in. at M = 218
Zc (in mils)
+30 +25 +20 +15 +10 +5 0 −5 −10 −15 −20 −25 −30 −35 −40 −45
N factors at M = 218 (W = 15 ft) → N0 (D0) N1 (D1) N1.5 N2 (D2) N3 (D3) N4 (D4)

Fig. 12. Slate 15, *The Black Swan*, as if shot by "human vision" with focus coupled to convergence so that D_1 = distance in ρ to plane of sharpest focus. Data as for Fig. 11. Curves 1–4 show successive convergence adjustments required for this shot (see text).

not be focused beyond 35 ft 9 in. for $M = 218$. However, the minimum convergence will alter with the size of screen for which the picture is shot, and the focal length of the lenses in use, which might give rise to awkward mechanical complications.

Much more serious than this, however, is the restriction on the depth range imposed by such a method of shooting, and — in the coupled arrangement — the undesirable and highly artificial pushing of things nearer and farther away in space, which will tend to negative the 3-D effect of the film, especially when complicated studio shots are undertaken. This can best be demonstrated by reverting to Slate 15 of *The Black Swan*, and showing how it would have appeared in space if shot by the "human vision" technique.

Figure 12 is a repeat of Fig. 11, save that it is extended to cover a higher range of nearness factors, and is marked with the actual distances found in Slate 15. Curve 1 shows the result of setting the back of the scene (13ρ) at infinity, i.e. at D_0, the method employed in the actual shooting. But now the front set of banners (at 79ρ) will come out to $N_{4.7}$, i.e. $(79 - 13)/13.97$, which is almost $\frac{4}{5}$ of the distance from the screen to any spectator. This is much closer than the cutting continuity allows, and, in the opinion of many, enters the region of eyestrain. Certainly, the extreme nearness of the banners would be quite out of keeping with the rest of the film. No other fixed setting is possible, since it would produce divergence on the back of the set, even with the extremely modest assumed magnification of 218 (i.e. a 15-ft image in the theater).

Thus a variable convergence for this shot is required by the "human vision" system under discussion, and we may conveniently assume that the convergence is coupled to the lens focus system in the way already described. The shot opens with the banners at 79ρ (6 ft 4 in.), and since at this distance, using a 50-mm lens at an aperture of $f/2.8$, the depth of focus is only about 17 in., it would be necessary to focus with some precision for the distance of the banners themselves. This would cause them to appear in the theater at N_1 (see Curve 2), and once again the wanted effect would not be achieved, though this time the banners would be too far away, instead of too near. As the first pair was lifted, the plane of focus would move gradually farther away, passing through positions such as Curve 3. Following accepted technique, the camera operator would follow focus in such a way that each pair of banners in turn would occupy the plane of sharpest focus; but this would have a disastrous stereoscopic effect, in that it would bring all the banners into the same image plane (i.e. on the screen), and thus would wipe out the wanted recession in space.

When the last banners had been raised, the focus would rest at 27ρ, and the back of the set would be correctly placed at 13ρ. But towards the end of the shot, Beryl Grey dances forward to 48ρ from camera, where she would be out of focus. It is therefore necessary to alter focus again, and according to normal practice, the dancer would be held in the plane of sharpest focus, shown as Curve 4 in Fig. 12. This would not only completely neutralize her forward movement in space, but would create divergence on the background, which would still be sufficiently in focus to be fusible. The only way out of the dilemma of neutralizing depth is to juggle with the depth of focus, placing very near objects at the limit of the zone of acceptable sharpness in order to correct as well as possible their misplacement in space. This procedure would unquestionably be much more inconvenient than having independently adjustable stereo settings for it would contradict accepted camera practice and would give rise to a method of shooting in which the sharpness of focus was always under suspicion.

The problem of divergence is even

more intractable. Figure 12 shows that points at 13ρ will be separated by 6.26 in. on the screen instead of the proper 2.5 in., which would induce serious eyestrain, especially for spectators in the front rows of seats. If the magnification is raised from 218 to 300 (i.e. a screen width of 20 ft 8 in.), the separation on background points would amount to 8.6 in., more than three times the separation of the human eyes. It should be remembered that divergence does not occur at all in natural vision; its physiological effect can be extremely uncomfortable.

Distortions With Fixed-t_c Systems

But this is not the last of the disadvantages of a "human vision" camera arrangement. The use of large B factors entailed by employing a value of t_e which is often too big for the size of screen and the depth range to be compassed, leads to serious distortion of the shape of objects, as may be seen by a comparison of the example worked out under "Image Distortion in the Theater," earlier in this paper, with the same scene shot according to the precepts of "human vision." The data will be exactly the same, save that t_e = 2.5 in. instead of 1.25 in., and that the dancer (who will be in the plane of sharpest focus) will be moved very slightly back from $N_{1.00}$ to N_1. When these new values have been substituted, along with the unchanged data, in Eqs. (11) to (13), the results in Table VI are obtained, which for convenience are placed alongside the characteristics of the shot in the film.

Table VI. *The Black Swan*, Slate 15, Stereo Distortions at the Plane of the Dancer's Final Position. M = 218; $V = 2.5W$.

	By "human vision"	In the film
m_d	12.4	4.9
m_w	3.4	3.1
μ	3.6	1.6

What has happened with "human vision" is that the width magnification has been kept down by making t_e equal to t, which is one of the conditions for ensuring that $m_w = 1$ (see Eq. (15)). On the other hand, the depth magnification has increased enormously owing to the squared term in Eq. (11), and this has more than doubled the distortion of shape, as indicated by the figures for the shape ratio.

This consequence of a "human vision" approach can be even more clearly demonstrated by the graphical technique already described. Figure 13 is in essence an enlargement of the relevant part of Fig. 12. It shows Beryl Grey's shoulder placed at 48ρ (10 ft 5 in.) from the camera, with arm outstretched as she pirouettes, so that the fingers are at 60ρ (8 ft 4 in.). The x-axis has been graduated in N values, so that the value of P (distance from spectator to a point in the image) can be readily calculated from Eq. (1). By taking two points, one at the shoulder and one at the fingertips, the actual stereoscopic length of the arm can be found by simple subtraction, in spite of the fact that the magnification varies nonlinearly between the two points. Figure 13 shows that the arm length, as shot for *The Black Swan*, is 102 in., whereas by "human vision" principles it would have been 208 in., or more than twice as great. The overall depth magnification works out as 4.1 in the first case, and 8.3 in the second, since the real arm length is 25 in.* As the dancer continues her pirouette, her outstretched arm moves into a plane parallel with that of the camera lenses, where its magnification will be uniform, and is given by m_w in Table VI. The two shape ratios are therefore 1.2 for the film and 2.4 for "human vision," which is again twice as much distorted.

* The overall magnification is of course lower than the magnification at the shoulder, because m_d decreases as N increases, and is therefore least at the fingertips.

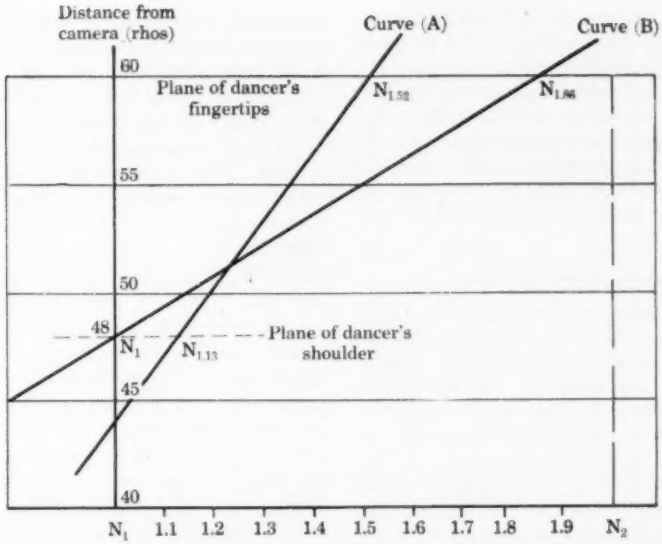

Fig. 13. Enlarged section of Fig. 12, with "human vision" rendering of Slate 15 (Curve B) compared with shot in film (Curve A). N values may be converted to image distances from spectator (P) by Eq. (1) ($P = V/N$). Assume spectator seated at $2.5W$, i.e., 450 in. from 15 ft screen. Let P = image distance to dancer's shoulder, P' to her fingertips, when her arm is outstretched to the spectator. Hence, stereoscopic length of dancer's arm = $P - P'$.

From Curve B, "human vision," $P = 450/1$, $P' = 450/1.86$, $\therefore P - P' = 208$ in.
From Curve A, shot in film, $P = 450/1.13$, $P' = 450/1.52$, $\therefore P - P' = 102$ in.

The general applicability of a "human vision" technique can perhaps be most quickly judged by a statistical summary of the t_c values employed in some recent pictures. The settings indicated by calculators such as the Stereomeasure and the Polaroid Interocular Calculator naturally give no preference to the value of 2.5 in., which is merely one setting in a wide and infinitely divisible range; but if, to give "human vision" all permissible latitude, we assign it the whole span of t_c values between 2.3 in. and 2.7 in., we can analyze its limitations in the light of actual t_c figures from productions. Picture A is a studio film shot in sets of normal dimensions; Picture B is a documentary film shot principally out of doors.

Table VII. Number of Shots Lying Inside and Outside the "Human Vision" Range for Two Typical Productions

	Less than 2.3 in.	2.3–2.7 in.	More than 2.7 in.	Total
Picture A	16	20	1	37
Picture B	6	10	29	46

Thus 46% of the shots in Picture A, and 76% of those in Picture B, fall outside the "human vision" range when calculated according to the general theory, and without any preconception that t must always equal t_c. It must be remembered that the scene we have been discussing in such detail is not in any way abnormal, but is representative of in-

numerable shots which try to exploit intelligently the possibilities of a properly conceived 3-D system. Almost any method of stereoscopic shooting will handle mid-shots and long-shots (in which the depth range in reciprocal units is not great) quite satisfactorily, and will handle all shots provided that they are projected on small screens of 8-ft or 10-ft width.

Limitations of Fixed-φ Systems

The scheme for equating t_e with t is by no means the only system put forward with the idea of simplifying and improving 3-D film making. Another typical arrangement is that of "Verivision," which has gained some currency in Holland, the home of its inventor, Dr. F. H. Reijnders,[11] who hopes to secure completely distortion-free reproduction by fixing the camera convergence angle permanently at $\varphi = 0.3°$.* At the same time t_e is made variable, and set at such a figure that the fixedly converged lens axes always intersect in the nearest plane of the scene.

It can readily be shown that "Verivision" (which disregards the effect of screen size) reduces to the simple relationship $D_0 = 0.44D_1$. This is graphed for distance increments of 10 ρ in Fig. 14, which clearly shows the possibilities and limitations of the system.† It has the advantage over "human vision" that, when the foreground plane is very close, t_e becomes very small and the depth range is correspondingly increased, as may be seen by the increasing gradient of the curves corresponding to the larger ρ values. On the other hand, whereas some scenes can be reproduced by "human vision" with freedom from distortion (i.e., when Eq. (15) can be satisfied), "Verivision" cannot possibly eliminate distortion except under one special and unlikely condition. Reference to Fig. 14 will show that all the characteristic curves intersect at a single point in the x-axis. To meet the first orthostereoscopic condition, $B = 0$, it is necessary that this point should correspond with N_0, and this, as the figure shows, occurs when $z_e = +20.5$ mils, which from Eq. (3) gives $M = 122$, corresponding to a screen width of 8 ft 4 in., a size not particularly well adapted to commercial production.

A further limitation of "Verivision" is that it imposes a method of filming which eliminates all N values greater than unity.

To sum up, it is incorrect to suppose that the functions of convergence and interaxial separation are interchangeable, and that either can be fixed at an arbitrary value without impairing the flexibility of the system. The B factor and the C factor are entirely distinct. Moreover, since the C factor cannot be altered after shooting (given the size of the screen), errors in t_e caused by incorrect filming methods cannot afterwards be amended.

* No explanation has been given for the choice of this particular angle, and Dr. Reijnders himself has prudently — though perhaps optimistically — claimed a patent on all values of φ between 0.15 and 0.6°.

† For purposes of comparison, the y-axis has been graduated with the values of t_e in mm obtained from Dr. Reijnders' formula for different values of D_1.

Part IV: Conclusions

Shooting a 3-D film demands two major changes in production methods: a change of attitude on the part of the director, and a change of camera technique.

The director of a 3-D film has an obligation to explore space relationships in his sets and between his characters which he would pass over in a normal flat film. If he neglects to do this, and merely em-

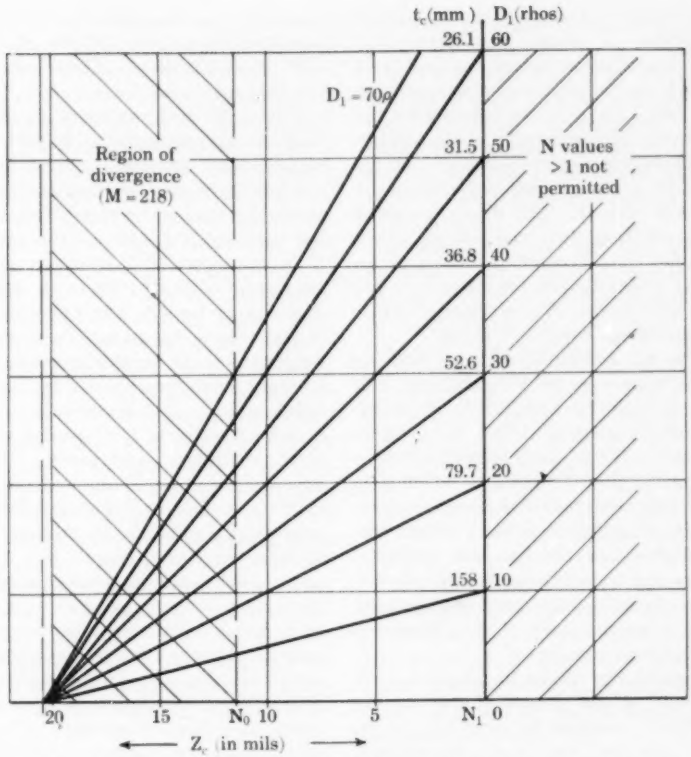

Fig. 14. Graphical analysis of "Verivision" technique (φ fixed at 0.3°, t_c adjusted so that optical axes intersect at D_1). Converging characteristics, shown at 10ρ intervals to 70ρ, show very limited depth range possibilities of the system, since only unshaded central area can be employed, and only that part of it bounded by available limiting values of t_c. Note that $B = 0$ only when point of intersection of characteristic curves occurs at N_0. This corresponds to $z_c' = 20.5$ mils, or $M = 122$.

phasizes the extra dimension by placing some meaningless post or tree or lamp-stand in the foreground of each shot, the audience will become as weary of these tricks as they became of the endless knives, ladders and hurtling baseballs of the pre-war anaglyphic pictures.

The left- or right-eye track of a 35-mm double-band stereo film may without modification be presented to a wider audience in unconverted theaters as a normal flat film. However, the more successfully the film's director has thought himself into the new world of the 3-D film, with its different space relations, rhythms of cutting, and use of optical effects, the less effective will be the flat version by comparison with what the same director would have made out of the same story had he concentrated on it alone.

The translation of the director's ideas into 3-D film demands a comprehensive knowledge of stereoscopic transmission theory — in just the same way as an electronic organ designer could not inter-

pret a musician's wishes without a proper grounding in audio engineering. A stereo transmission theory has now been evolved, some elements of which we have described; and to it has been added the beginnings of a new study of the psychological aspects of stereo viewing — corresponding in our analogy to a study of the modes of hearing. This theory is framed in a carefully studied terminology, which we hope may become the basis of an agreed nomenclature, for much time has often been wasted in new subjects by discussing names instead of things.

Once the transmission theory and the terminology have been established, calculators may be designed and stereotechnicians trained, so that the production of a 3-D film takes very little longer than a flat film. Spatial effects can be controlled with positive assurance, sets can be designed to achieve effects unobtainable in the flat film, and back projection and traveling matte processes can be developed with accurate knowledge of what is needed and of the tolerances which have to be met.

These things cannot be fully achieved, however, if the design of the camera has been cramped by artificial restrictions on the two main stereoscopic variables. Pictures which are shot for projection to small nontheatrical audiences are indeed much less critical than pictures shot for the big screens in commercial theaters. The former may perhaps prove satisfactory if calculated by rule-of-thumb methods; for the latter much greater precision is needed if professional standards are to be met and audience discomfort and eyestrain avoided.

Mathematical analysis is needed as a tool of space control in the filming of 3-D pictures because the mental construction of a space image from data originally incorporated on two pieces of flat film bears only a remote resemblance to the human process of seeing objects "in the round" as they exist in the external world. From this analysis, as we have seen, flow important consequences relating to the design of 3-D film cameras. These may be summed up as follows.

When M is large, and f_e, in the interests of composition, is under the cameraman's control, t_e must be adjustable over a wide range, and in particular it must be capable of assuming very small values (of the order of 1 in., or even less) to make possible interesting camera effects of extreme depth range both in the studio and outdoors. Large values of t_e are essential for getting a big depth content on small screens, and for producing startling space effects on large ones.

A fixed value of t_e eliminates most of these possibilities, and greatly exaggerates the distortion of objects to which a stereo system is in any case prone. If convergence and focus are coupled, other undesirable effects make their appearance: following focus helps to negate the movement of the camera through space by bringing everything in the foreground into the plane of the screen; at the same time it becomes almost impossible to give near objects an N value much greater than unity, since they will automatically go out of focus in the attempt. But large N values — quite apart from their occasional use as stunts — are essential to the bringing of the picture close to every spectator, which is one of the outstanding advantages of the space film.

A fixed value of φ has equally little logic to support it, and it takes the control over the position of the image in space out of the hands of the cameraman and director to whom it belongs, and fixes it in accordance with some partial or erroneous theory.

By contrast, the general theory outlined in this paper — unlike the patented procedures discussed in Part III — does not prescribe any fixed camera technique or impose the use of any mechanical device. The director and cameraman should be able to make a free choice of the space effects they require the ulti-

mate audience to experience; the stereotechnician will then be able to tell them how that effect can be produced, provided that the camera equipment is sufficiently flexible and that psychological viewing factors are properly taken into account. A true parallel, therefore, would be with the science of sensitometry, which does not attempt to prescribe fixed exposure settings, but does in fact analyze the consequences of making toe and shoulder exposures, altering the developing time, using different types of emulsion, and so on.

In the same way, a valid transmission theory will enable the stereotechnician to determine what will be the geometrical form and position of the space image under all possible camera, optical printing, projection and viewing conditions. The effects of altering the space structure of the image in passing from shot to shot, as well as the space distortion in individual shots, which are revealed by this analysis, will be evaluated in the light of previous experience in seeing 3-D films. Not only will the members of the production team themselves become increasingly sensitive to the appearance of a new kind of film image, they will come to know what is and what is not effective in terms of audience response.

Already a substantial body of production experience has been built up in the last two years in the course of developing and applying the principles outlined in this paper. A dozen films have been produced which have been commercially exhibited in half as many countries and seen by audiences now nearing the 3 million mark.

If the full possibilities of the 3-D medium are to be exploited, the design of new cameras should be put in hand forthwith. Both theoretical analysis and experience point to the need of a wide flexibility in the t_e and h variables, and of a precision of adjustment and film registration equal to that which must be attained in 3-strip color cameras. By using separate 35mm films for the left- and right-eye images, and by interposing the minimum number of additional glass surfaces between scene and film, these requirements can be achieved, though there is at present only one camera in the world (the work of J. A. Norling) of adequate precision and flexibility.

Granted adequate cameras, there is no reason why films as ambitious as any now made in Hollywood should not be undertaken in the vastly more powerful 3-D medium. The knowledge thus acquired of production problems and audience response would remain of undiminished value were polarized projection to be replaced in the future by some type of integral or "free-vision" viewing screen; for though the means of separating the images may change, their appearance in space is likely to remain unaltered. For example, the parallax barriers recently classified by Kaplan in a paper of fundamental importance,[12] one and all give rise to an image geometry identical with that already analyzed in Part I for a plano-stereoscopic system.

As long as audiences will, therefore, accept for the time being the slight inconvenience of glasses — which recent European experience seems to bear out — there is no reason why major studios in the U.S. and Britain should further delay the production of at least a few dramatic films to determine whether or not they are the answer to a declining box office.

At the same time, other developments in the projection field will be under way, which will still further close the gap between the spectator and the scene, and will reinforce that sense of participation in the drama of a film which alone, perhaps, can prevent the great audiences in the motion picture theaters from dissolving away into little audiences in front of home television screens.

Acknowledgments

For the material of Part II, the authors wish to express their gratitude to the staff of Anglo-Scottish Pictures, coproducers with Stereo Techniques, Ltd. of *The Black Swan*, and especially to Leonard Reeve, the director, Bernard Davies, who bore patiently with the camera, and Alvin Bailey, the editor. Our thanks are also due to Brian Anthony, head of the Optical Department, Denham Laboratories, who carried out the stereo corrections on *The Black Swan* and a number of other pictures.

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Drawing in Three Dimensions for Animation and Stereoscopic Processes

By ERNEST F. HISER

Stereoscopic mathematics are far too complicated to apply easily and speedily to every point in the many drawings and cells required to obtain motion in animated films, or in a usable volume of art for commercial or lecture purposes. The following procedure was developed to allow stereo drawings to be made with a minimum of time and effort and still produce practical three-dimensional material.

IN THIS METHOD the artist draws to scale directly from the subject as in conventional art practices but also adds the scale distance he may be from the object, as well as the depth of subject measurements, to obtain stereoscopic effects. He is able to compute the amount of stereo depth necessary in any part of the drawing; and he is able to determine the size of the image which will appear on the screen. Stereo rules and principles as outlined in this paper do not necessarily apply to true stereoscopic mechanics, as these practices were developed only while making this simplified procedure workable. Single objects for advertising and lecture purposes drawn in stereo differ from scenic stereo art in that they are usually small in size and show considerable detail without much height, width or depth. This necessitates special consideration when preparing them for three-dimensional viewing.

A contribution submitted June 25, 1952, by Ernest F. Hiser, Dept. of Medical Illustration, School of Medicine and University Hospitals, The University of Oklahoma, Oklahoma City 4, Okla.

Figure 1(a) shows the left (L) and right (R) eyes from above, looking to infinity with parallel lines of sight. While it is optically possible to widen these twin lines to some extent, natural visual adjustments do not depend on this ability. Stereoscopic vision is practically nonexistent beyond 1000 to 1500 ft, but from 200 ft to within a few inches of an observer the portrayal of a third dimension becomes a very noticeable accomplishment. The parallel sight lines indicated are the width of the eyes, a maximum of $2\frac{5}{8}$ in., and for all practical drawing purposes that figure is used.

Any object within the range of stereo vision will cause the eyes to converge or "toe in" just enough to focus on that object and its particular point of interest. While this point of interest is actually a point, a vertical flat plane at that point is important in this method of making stereoscopic drawings. This flat plane is to be considered as the "window-plane," and is located exactly where the

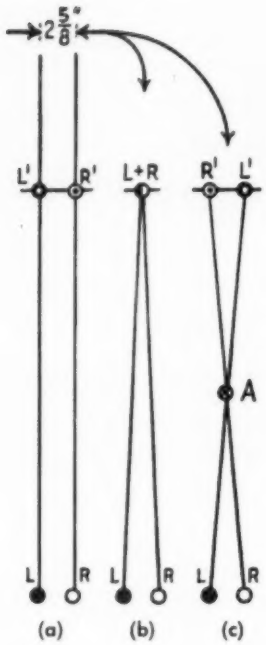

Figure 1

viewing screen will be upon projection, or where the aerial image appears upon viewing by other methods. The point of focus or interest for any object can be at any depth level within the boundaries of that object. The term "window-plane" derives from the fact that in a stereo picture all objects appear to stand out or recede from the black edge of the picture as if they were being viewed through a picture frame, or window.

Although the point of focus may be placed on any part of the subject for emphasis, a dead-center location will give the maximum overall stereoscopic effect for the subject. When the picture area includes several objects, a dead-center point of focus will provide excellent depth separation. All objects drawn to the front of the window-plane will appear nearer to the observer, while all objects drawn to the rear will appear farther away. This plane interposed into a stereo scene with the eyes set at infinity will cause the sight lines from L and R to pass through it as L^1 and R^1 ($2\frac{5}{8}$ in. apart), and the two flat drawings which constitute one stereo drawing will have their identical components separated by that scale distance on the window-plane.

In Fig. 1(b), the lines of sight are toed in until the point of vision is focused upon the window-plane. All points on one drawing which are to appear on this plane will coincide exactly with the same points on the other drawing.

In Fig. 1(c), the point of focus is brought forward to A, where the toe-in or crossing of the eyes causes the lines of sight to project upon the window-plane as R^1 and L^1, and in reverse order to that of infinity. As there is a limit to the toe-in effect (with the danger of obtaining ghost images), this amount should again be not more than $2\frac{5}{8}$ scale in. on the window-plane. The point where the sight lines cross, A, will always be exactly one-half the distance of the window-plane to the observer. Since the coincidal points of focus are separated by toe-in as in (b), the object focused upon will appear nearer to the observer.

In order that these measurements be made practical, it is essential that the screen size is visualized. A 40-in., 6-ft or 18-ft screen with a well placed and planned image size must be kept in mind throughout the process so that parallax on the window-plane can be computed easily for its comparative to scale likeness on both drawings.

The first drawing to be made can be designed without too much regard for stereo principles. It should have correct perspective, and the heavier lines should be drawn to the front of the subject as in accepted art practices, with the lighter lines to the rear giving an illusion of depth or roundness to the drawing. This illusion of depth in the first drawing can be intensified to advantage in this type of work. A good stereo drawing is

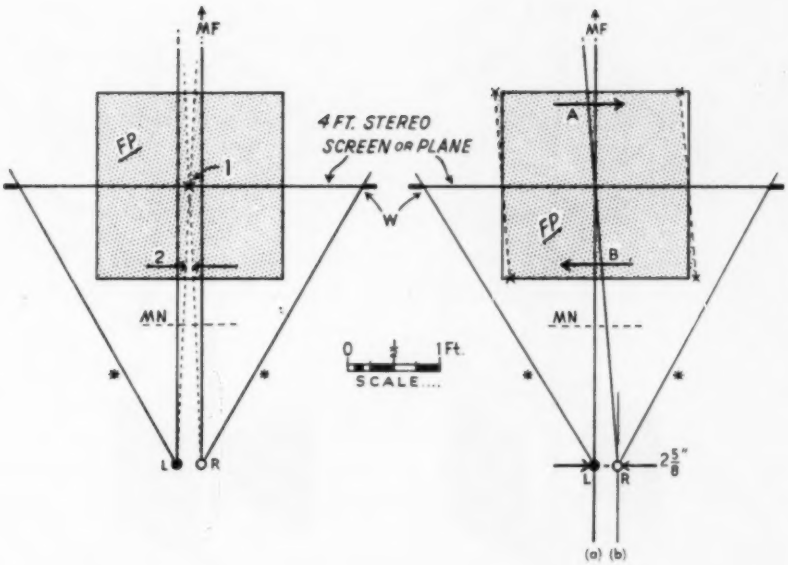

Figure 2

Figure 3

finished when a satisfactory delineation of the subject is obtained in the rather stiff and hard-outlined techniques peculiar to animation. In this process the first drawing is always called "L," or "the left-eye drawing" for convenience and to avoid confusion when many drawings are at hand.

Figure 2 is an extreme example with an extra-large subject, and shows the approach to the second stereo drawing while illustrating the first step in sketching a 2-ft transparent cube as it would appear in stereo from a distance of 3 ft to the artist; the focal point selection is dead center. The picture is to be shown on a 4-ft screen. The L and R eyes are placed at scale distance in scale inches apart below a cross section of the subject. (FP is the floor plan of I, the completed left-eye drawing). Vertical lines of sight to infinity show where points of vision cross the window-plane, or screen. MN and MF are the "maximum near," and the "maximum far" limits which can be drawn with the point focus in the center as indicated without causing eyestrain or ghost images. These limits increase as the distance from the artist to the subject is increased, and it is obvious that as these limits increase so does the depth of the entire picture. Infinity backgrounds may be added to assist further in depth perception. MN is exactly halfway between the window-plane and the observer, while MF is the same distance on the other side of the plane. Lines marked * are the outside limits of the picture as a whole, and run from the eyes to W — the edges of the picture or window-plane. MN and MF will always place L and R $2\frac{5}{8}$ in. apart on the window-plane.

Lines drawn from L and R through the subject area and crossed at the point of focus (1), will indicate the amount of shift (2), or line displacement, necessary for both near and far stereoscopic effects *within* the cross section.

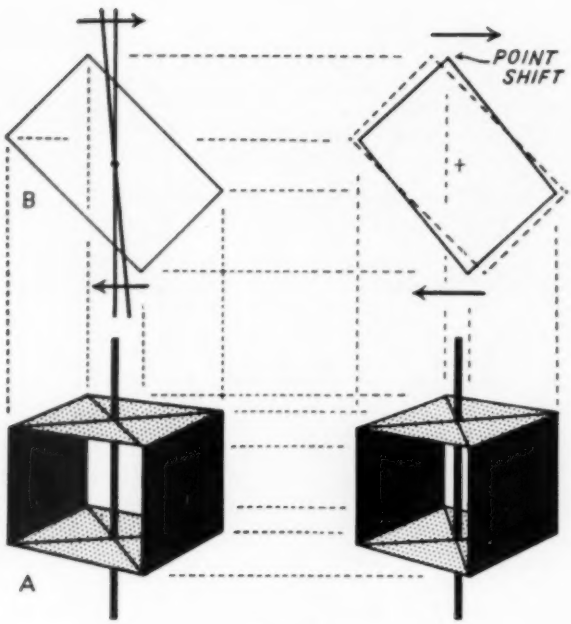

Figure 4

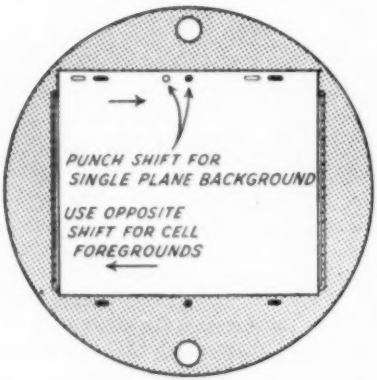

Figure 5

For further simplified operation, Fig. 3 shows that the amount of shift can be estimated quickly by a simple crossing of the L sight line at the point of focus by the R sight line. All points to the front of the focal point, as well as those at the rear are to be offset in exact proportion to the width of the shift-cross or scale, and in the direction of the corresponding arrows A and B. It is obvious that this shift will be greater or narrower in width as the distance L and R is nearer or farther away from the window-plane or focal point. Lines (a) and (b) are a reminder of the maximum separation that can be made for near and far objects.

Figure 4 illustrates a simple object with exaggerated drafting for easy visualization of the mechanics of the shift-scale, and brings the problem to completion for both L and R drawings. A is the original, or L, drawing. B is the cross section of the object with exaggerated shift-scale in place and with all major points projected over to the right where the cross section is duplicated. Point shifts are measured in accordance with the proportional widths of the shift-scale, and a

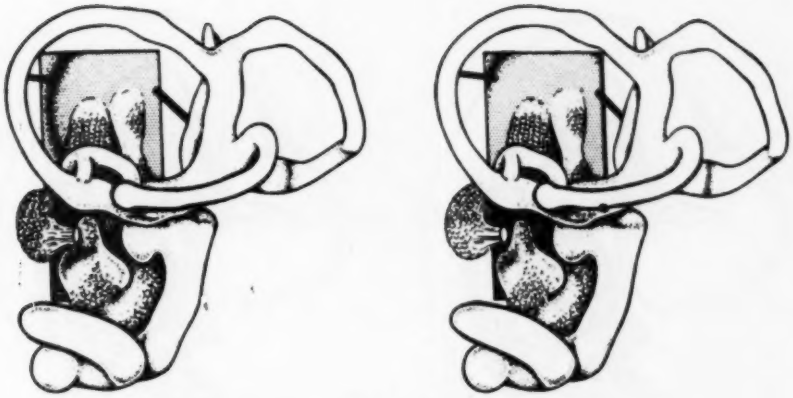

Figure 6

new, or right-eye cross section is superimposed over the L cross section. Lines are projected down from all points to complete the R stereo drawing.

Additional cross sections should be made of any part of the subject which changes contour, and from which point shifts can be measured from the shift-scale. It is possible when drawing consistently on the same distance scale (as in animation) to estimate the R shifts on either side of the point of focus by the eye alone with considerable accuracy, as soon as the near and far shifts of the scale are known for the object being drawn. Exaggerations for special emphatic effects in both near and far points of interest can be obtained by increasing or decreasing the shift-scale measurements to unbalanced amounts. The shift-scale should be drawn in perspective as in the subject when the scene is large enough to include noticeable perspective.

When a flat-plane background is to be located at any point between the back limits of the subject and infinity, only one drawing is necessary. In this case the paired L and R drawings are made on cells for use over the single-drawing background. This background will need a stereo-shift in proportion to the desired depth in the scene which is accomplished on a standard animation board, as in Fig. 5. The background paper is punched twice to proper offset measurements for the L and R image shift and is used underneath the corresponding cell to complete either the L or R assembly.

Subject parts may be labeled at their different stereo levels, and flat-plane foregrounds and details may be added in this manner to complete a scene without working on the main L and R drawings. The labels or details are drawn on cells which are double shift-punched for the correct plane, and are placed on top of the background and L or R assembly for photographing.

Figure 6 is a scientific stereo drawing made with a back mount for the subject simulating a background, a device which sometimes assists the observer in obtaining good stereo vision. Figure 7 is a drawing without a supporting background, and in this case the stereoscopic effect depends entirely upon the shift drawn in the R-eye drawing. Actually, the R drawing is the only one where depth measurement and shift are necessary. Entire animation sequences can be drawn first as for regular animated films, can be checked for timing and accuracy, and be otherwise completely finished before the R-eye series is begun.

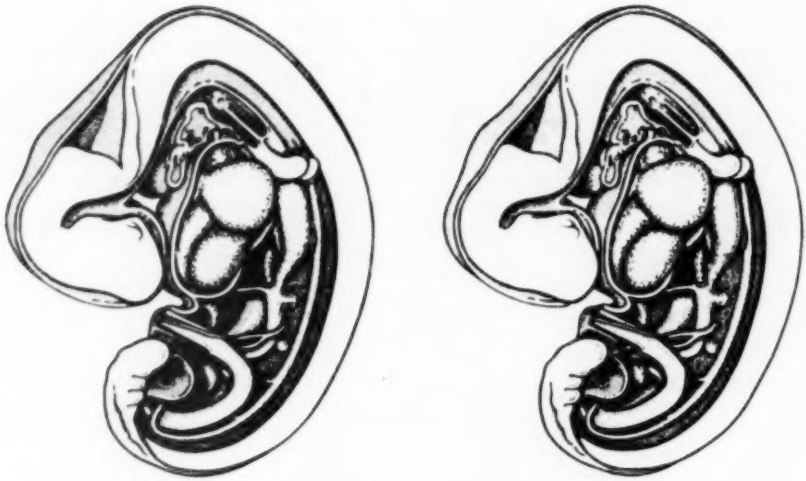

Figure 7

In cases where old two-dimensional films can be shown to advantage stereoscopically, the original drawings can be used as the entire L series.

The process of photographing the completed stereoscopic drawing assemblies depends upon the equipment available and the aims of the project. As there are several good procedures, the one currently in use will provide the method necessary to turn the completed work into practical commercial, teaching or lecture material.

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Animation for Individual Television Stations

By ERNEST F. HISER

With the advent of television and the consequent increased use of the animated film for advertising, it has become necessary to devise quick and inexpensive methods for the small studio to produce such films. In this paper some simplified techniques for animation are described.

THERE IS no need to discuss or evaluate the use of animated films as an advertising or spot-announcement medium. The problem is, how can such work be produced by the average small studio art department at a time and price ratio that will allow for speed, revamping, and the visual appeal necessary for local and short-contract sponsors? Farming out films to commercial firms with their expensive production methods may be desirable but is out of the question unless the sponsor or department contemplating the work is fortunate enough to have funds warranting such productions. Simpler and cheaper methods of animation must be devised if this medium is to be utilized to full advantage.

No claim is made for extensive originality in presenting these animation techniques. This paper was primarily designed to present routines capable of producing usable film material as speedily as possible. Comparatively simple or simulated animation can be prepared after one has made a study of "stop-motion"—the basis of all animation. Throughout this paper, the term "animation" will be used to indicate all phases of stop-motion.

The staff artist does not need to be a photographer to do animation, as the photographic part of the process is mostly a fixed thing, and all camera operations necessary for the methods used are easily applied. Figure 1-(1) shows a simple camera stand with an interchangeable animation board which will work equally well under the camera and over the illuminated tracing table. Using the same board for two purposes will also eliminate error in register and layout.

It is well to remember that the *effect* of animation is the aim, rather than true animation, and that the effect processes cannot encompass some types of fluid motion. To obtain smooth motion in human and animal figures, or similar

A contribution submitted on June 25, 1952, by Ernest F. Hiser, Dept. of Medical Illustration, School of Medicine and University Hospitals, The University of Oklahoma, Oklahoma City 4, Okla.

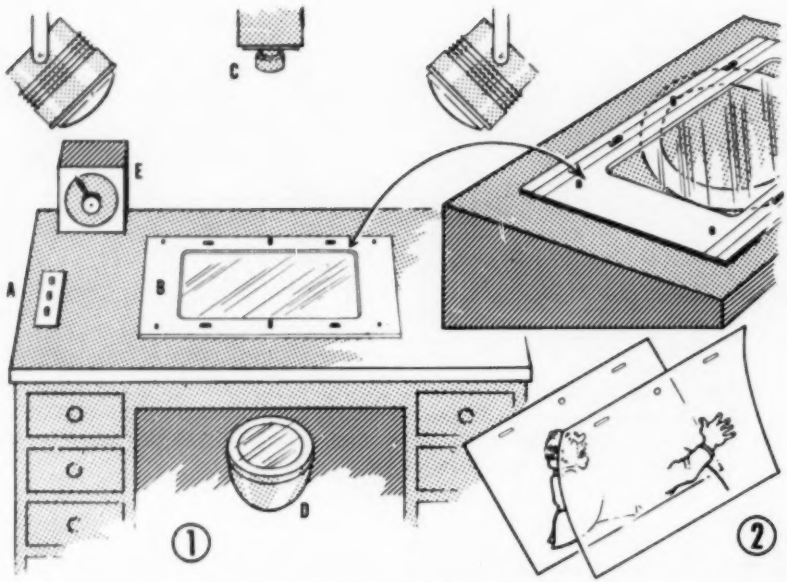

Fig. 1-(1). A, animation stand complete; B, animation board on pegs under camera (the same peg holes fit on tracing table at right which is illuminated by circular lamp); C, camera; D, lamp under animation stand for transillumination; and E, transformer for laps, fade-ins and fade-outs.

Fig. 1-(2). Method of drawing on paper with cell overlay.

complicated multiplaned objects, drawings such as those made by commercial animators will have to be approximated. Although it is possible to simplify these units to a great degree, too much simplification will produce an effect so amateurish that an entire sequence may be spoiled.

The "story" of the action, whether it be for a chart, graph or complicated pictorial delineation must first be broken down into scenes or action units as one would imagine them on the screen: titles, sound, action, etc., in proper order. Along one side of this script little sketches are made at each change of scene or action tempo. These assist in visualizing the film, and form a basis for determining the overall mechanics of timing and the animation methods to employ. This layout is called the "storyboard" (Fig. 2).

The artist "times" the action by imagining that action as taking place, even going so far as to draw rough graph lines and details as he would have them appear for each little sketch on the storyboard. With the help of a stop watch he marks the times obtained in seconds on each sketch, as well as after each legend, rest and title. The soundtrack wordage is also timed and balanced against the animation timing at this stage of the production. The artist will now be able to add "holds," or places where the action stands still, to his script while commentary wordage continues. It is seldom necessary to have continuous action throughout a sequence, in fact, holds are desirable for

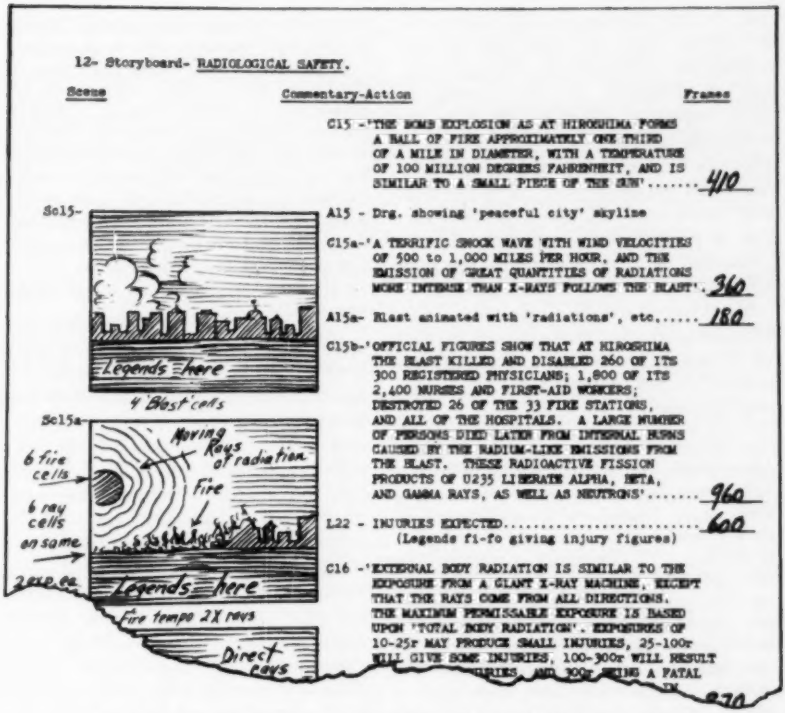
12- Storyboard- RADIOLOGICAL SAFETY.
Scene
Commentary-Action
Frames
C15 -'THE BOMB EXPLOSION AS AT HIROSHIMA FORMS A BALL OF FIRE APPROXIMATELY ONE THIRD OF A MILE IN DIAMETER, WITH A TEMPERATURE OF 100 MILLION DEGREES FAHRENHEIT, AND IS SIMILAR TO A SMALL PIECE OF THE SUN'..... 410
Sc15-
A15 - Drg. showing 'peaceful city' skyline
C15a-'A TERRIFIC SHOCK WAVE WITH WIND VELOCITIES OF 500 to 1,000 MILES PER HOUR, AND THE EMISSION OF GREAT QUANTITIES OF RADIATIONS MORE INTENSE THAN X-RAYS FOLLOWS THE BLAST'. 360
A15a- Blast animated with 'radiations', etc..... 180
Legends here
4 Blast cells
C15b-'OFFICIAL FIGURES SHOW THAT AT HIROSHIMA THE BLAST KILLED AND DISABLED 260 OF ITS 300 REGISTERED PHYSICIANS; 1,800 OF ITS 2,400 NURSES AND FIRST-AID WORKERS; DESTROYED 26 OF THE 33 FIRE STATIONS, AND ALL OF THE HOSPITALS. A LARGE NUMBER OF PERSONS DIED LATER FROM INTERNAL BURNS CAUSED BY THE RADIUM-LIKE EMISSIONS FROM THE BLAST. THESE RADIOACTIVE FISSION PRODUCTS OF U235 LIBERATE ALPHA, BETA, AND GAMMA RAYS, AS WELL AS NEUTRONS'..... 960
Sc15a-
Moving Rays of radiation
6 fire cells
Fire
6 ray cells on same
L22 - INJURIES EXPECTED..... 600
(Legends fi-fo giving injury figures)
Legends here
Fire tempo 2X rays
Direct rays
C16 -'EXTERNAL BODY RADIATION IS SIMILAR TO THE EXPOSURE FROM A GIANT X-RAY MACHINE, EXCEPT THAT THE RAYS COME FROM ALL DIRECTIONS. THE MAXIMUM PERMISSABLE EXPOSURE IS BASED UPON 'TOTAL BODY RADIATION'. EXPOSURES OF 10-25r MAY PRODUCE SMALL INJURIES, 25-100r WILL GIVE SOME INJURIES, 100-300r WILL RESULT
270

Fig. 2. The storyboard, with working data and times computed.

visual observation of scenes showing a sponsor's product, etc.

The amount of film necessary for the production can then be estimated from the total number of seconds or frames obtained. As sound film is projected at the rate of 24 frame/sec, the number of drawings required and the measurement of line displacements necessary for smooth motion can also be calculated from these timing figures. Some action speeds or drawing advances will require a two-frame exposure for each drawing, while others will use more or less exposures for smoothness of action. Caution must be used in the preparation of the exposure figures: it is very easy accidentally to clip off a few words of commentary, or to allow action to proceed too fast—or to drag along—upon the television screen.

Drawings for television should be made on paper which has a decided tone, so that unpleasant smears will not occur on the screen. On all work of this kind, pure white of any type should be used sparingly if at all. The art work should be somewhat stiff and hard, with considerable emphasis on contrast. Soft, delicate drawings may be used for background work in some instances, although detail cannot be followed easily by the viewers when this type of art is in motion.

Every phase of motion in the story need not be animated. When the action is very obvious, such as in the opening of a package, gadget manipula-

tion, or the placing of many objects in the scene, numerous drawings can be avoided by fading-in the change with laps or dissolves. A little arrow or other indicator pointing to the approaching fade-in phase area will focus attention on the spot so that the desired effect will not be missed. It is possible, with much hard work and many drawings, to produce such fancy and intricate animation at a critical point that the subject matter is lost to the observer.

Examples of simple animation can be demonstrated by a conventional display ad or catalog layout, i.e. a drawing with several legends and indicator lines upon it as follows:

a. The drawing is to appear first without catch lines. These appear singly with a little arrow pointing to the corresponding area. Each legend and its arrow vanishes for a second or two before the next legend appears. . . . This effect is obtained by the use of little lettered cards for the legends and a single cutout arrow which are placed in position on the drawing before each exposure. Rests of one or two seconds are exposed between the legends. A piece of clear plate glass is placed over the assembly during exposure to make the items lie flat and smooth. Single-frame camera work is not necessary unless the number of frames exposed must be exact.

b. The drawing is again to appear first without legends. This time the legends appear singly as before but remain in the scene once they appear. Corresponding indicator lines run from each legend directly to the point in question. In this case the lettering and lines are done on a celluloid overlay, or "cell." This cell is put in register over the drawing so that the assembly appears complete, as at the end of the sequence. The drawing is placed upside down under the camera, and the scene is photographed *backwards*, that is, by scratching off the lettering and lines from the cell one at a time with a blunt point while reading the timing figures on the storyboard in reverse order. The artist ends with only the drawing remaining under the blank cell. After this section of film has been processed it is reversed (turned end for end) for projection, and the effect will be as desired.

c. Dotted or solid lines encircling any particular area on the drawing for emphasis may be made to appear by this cell-and-reversal method either by "flashing-in" the line as a whole, or by causing the line to "draw itself in," which is accomplished by scratching out only a small portion of the line at a time while using evenly timed single-frame camera exposures. Again, the timing or exposure sheet is read in reverse for correct filming and effect.

Basic graph or chart forms and photographs may be used instead of drawings for the master background, and lines, lettering, figures, etc., may be made to appear as desired by this method. Two cells can be used over a background at the same time when separate action lines cross each other or when the subject matter is more complicated. Scratchboard can also be used for the background when additional scratch-off work is necessary. The animator can visualize many variations of this process to apply to any story situation if he will take the trouble to lay out and time a sample storyboard for a sequence which is to appear as above.

Layouts using black backgrounds are sometimes permissible for various types of work, especially when light or colored lines and lettering constitute the bulk of the copy. A good black is not always easy to get from a photographed card; and painted-out, scratched-out or covered-up lines are apt to show up as such. One way to avoid this trouble is to make the original layout in black on white paper. A *litho negative* is made of this drawing in the proper size for animation. Lines, detail and copy are drawn with transparent color as desired on this negative. It is placed in upside-down position under the camera as before, with a lamp underneath the transparency ready for transillumination. All top lamps are switched off. The lines are then painted out in reverse

storyboard order with a matte black watercolor. This process gives a true black background with brilliantly colored detail, and will show no evidence of construction upon construction. Such work when photographed on color film will produce the necessary grays for black-and-white television projection and will also provide a film for future color television.

It is a good idea when working in color for black-and-white projection to photograph a frame or two of each color in the brand of paint used and make a gray scale from these tests. As few colors photograph exactly as they appear on a card or on celluloid, this test will also serve as a guide for art work designed to be shown in color.

The above method is also invaluable for fast, easy production of line diagrams or pictorial "growths" when a black background can be used. It is also valuable for title work and designs which "draw themselves." In title work using color, the black background can be changed to any color desired by winding color film already exposed for the title back in the camera to the beginning of the title and double-exposing a piece of colored paper over the shot already made. A good paper to use for many effects in animation is artist's pastel velour, which will not reflect highlights because of its matte surface. During photographing, the transillumination lamp is, of course, turned off and the top ones turned on. This method is limited only by the animator's imagination, and will produce many color effects from any black-and-white original.

Cutout overlays may be utilized in many ways to supplant a drawing, photograph or chart, and to add interest or detail to any type of scene. These cutouts must be made accurately to register exactly with the drawing underneath. Cutouts should be made on opaque paper and have their edges blackened before use. To register correctly, cutouts are cemented to acetate cells with rubber cement, which will not cause wrinkles or waves in the cell. When registered on a regular animation board with its registering pins, assembly will be easy and successive phases will match line for line. Legends and indicator lines may be inked in on the same cell as the cutout.

The first form of animation as invented by Winsor McKay consisted of a series of drawings with subject and backgrounds complete, and with action similar to the little "flip" books for children. This type of animation was very difficult and time-consuming, as tracings of all lines had to be extremely accurate in all parts of the drawings. In this type of work the lines and detail which stood still for some time were subject to a definite "shimmy." A variation of this process is still used when every part of a drawing is undergoing a continuous change.

Fluid-motion animation is best handled in pen-and-ink outline with considerable contrast in shading or coloring. Any part of the drawing which does not move, even for a short time, should be made on a cell to eliminate work and stabilize the action. When no background is needed, the action is drawn on toned or colored sheets of paper plus the required number of work-saving cells. When the background is an inherent part of the scene, or continuous fluid motion is required over a combination layout, all action is drawn on cells. The lines and outlines are inked in on the front of the cell, and opaque color is painted within the outlines from the back, which preserves the sharpness of the inked lines and provides opacity to the cell. Action may be drawn on paper and transferred to cells as in the cutout method if desired, since the results will be the same (Fig. 1-(2)).

In animating any action the "extremes" — the first and last drawings of the scene or action phase — are sketched

first. A study of the action will then show which parts of that action will require emphasis or near-stops between the extremes. With these drawings made, the animator then has the first and last drawings as well as the major in-betweens of the contemplated action, and the assembly will appear as a series of drawings showing the major phases of a subject such as might be prepared for publication in an advertisement or article.

The storyboard will then show how much time is to be consumed between these majors. Dividing the times obtained into frames will give the proper line displacements or advance necessary on each drawing for correct and smooth action, as well as the final number of drawings required to fit the action. It is well to keep in mind the fact that the more drawings there are to be made for a certain action (involving the *least* line displacement) the smoother that action will be. If the number of drawings actually required is considerably decreased, line-displacement distances on consecutive drawings must be *increased* and a greater number of frames exposed for each drawing. These increases can easily result in a very jumpy sequence.

Slow or gradual changes are generally preferable in advertising and lecture films, and, at sound speed, a $\frac{1}{8}$-in. line advance with a two-frame exposure on a drawing which has a working field of approximately 8 × 10 in., is about the greatest advance which can be made between drawings without obtaining an irritating jumpiness. Even this does not appear too smooth at times when great contrast is encountered in art work. A $\frac{1}{4}$-in. advance with a single-frame exposure will have much smoother motion, although the tempo might be a little fast. It is always better to make a few extra drawings than to have the action pass by too quickly or shimmy badly because of excessive exposures.

After the majors and in-betweens are prepared the drawings are checked for all lines and components which will stand still for any length of time during the action. These lines are drawn on cells for stabilization and elimination of shimmy. Although regular commercial animators use a complicated three-cell arrangement it is seldom necessary to go beyond one cell for simplified advertising and spot films. When even one cell is used over a background or for work-saving reasons, it will be necessary to expose all drawings of that series through the same number of blank cells before and after the cells are used because of the extra tone imparted to a scene by any cell overlay.

After the cells are made, the extremes, majors and in-betweens on paper are inked in (minus the lines on the cells). In finishing the in-betweens it is not necessary in fairly rapid action to obtain the same degree of exactness in draftsmanship as on the majors, although the line displacements must be accurate.

Each drawing is then marked as to consecutive number in the scene, number of exposures required, the number of the cell which must accompany it, and any other data considered important to the animator.

To eliminate excessive background area, or to localize action or interest, a foreground can be made of colored velour paper with a round or otherwise suitable opening in it for the action to show through. This foreground is placed over the drawing assembly on the registering pins before exposure of the scene.

The above basic production methods are as near to actual commercial animation as the television animator needs to go for the production of ordinary local film needs, and by using one or all of the above — even in one sequence when they will blend together — much valuable material can be designed. The effect or presentation of the subject is all that matters; the manner of obtain-

ing that effect is secondary as long as the methods employed do not result in a visual hodgepodge of artistic media without advertising or story value. Once more, the entire effort depends upon the design of the storyboard — the blueprint of the production. If the storyboard has been carefully drafted with full regard to the story, and timed with a view to good presentation, an overall technique will become apparent which includes one or more of the above processes of simplified animation. The method using the least amount of art work should be selected whenever possible, as in many cases the simpler technique will present the subject more graphically than will the complicated one.

Animation should only be used when the subject cannot be presented by regular photography, or when a new method of approach, unusual effects, or the presence of artistic values can play an important part in the instructive aspects of the advertisement or story. Animation should also be used as an adjunct rather than as the principle illustrative medium unless the entire subject benefits by graphic animated pictorialization.

X-ray Motion Picture Techniques Employed in Medical Diagnosis and Research

By S. A. WEINBERG, J. S. WATSON, Jr., and G. H. RAMSEY

With Appendix by W. E. SCHADE

X-ray motion picture techniques are reviewed with attention to relative exposure requirements and ability to record detail. Direct cineradiography on full-scale screen-films provides the best reproduction of detail but does not at present reach true motion picture speeds. Cinefluorography is the most flexible and least expensive of the traditional methods. Because of harmful effects of radiation cinefluorographic examinations of human subjects must generally be limited to a relatively few seconds. The length of examinations can be much prolonged with the help of screen image intensification. Unfortunately the x-ray motion pictures made by kinescope recording are not yet satisfactory from the point of view of detail.

THERE ARE a number of ways of making x-ray motion pictures, each one of which has its special virtues and limitations:

1. Successive frames of film are exposed directly to the x-rays which have passed through the subject.

2. Instead of being exposed directly to x-rays, each frame of double-coated film is compressed at the moment of exposure between a pair of fluorescent intensifying screens. Excited by x-rays, the screens emit violet and blue light, thus exposing the film.

3. A fluorescent screen is set up perpendicular to the x-ray beam as in fluoroscopy. The image formed on the near side of the screen is copied by a motion picture camera to a much reduced scale.

4. The screen image is picked up by a television camera, and a kinescope recording is made of the action. This method is still in the experimental stage.

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Direct Cineradiography Without Intensifying Screens

Methods 1 and 2 are generally referred to as direct or full-scale cineradi-

ography. In both cases the shadow image on the film is a little larger than the subject; and in this respect the methods are alike. There is, however, a striking difference between them in the matter of photographic speed. Mainly because of the poor absorption of hard x-rays by the film emulsion, an examination recorded on single-coated film without screens, at diagnostic kilovoltage levels, may require 25 or 50 times as much x-ray intensity as a similar examination recorded with the aid of intensifying screens. Method 1 is, in fact, so "slow" that its use is confined to small, easily penetrable subjects of thin cross section. The subject, a worm or insect,[1] the thorax or abdomen of a mouse,[2] is positioned in front of the aperture of a 35mm camera, and the x-ray beam is directed through the subject to the film. During the pulldown phase of the camera the film must be protected from x-ray fogging, either by reinforcing the shutter with lead or by interrupting the primary circuit of the x-ray generator.[3] It so happens that the ability of the unaided film emulsion to resolve fine detail is relatively very good. This is fortunate, because the significant detail of small subjects approaches the microscopic.

Direct Cineradiography With Intensifying Screens

With the aid of intensifying screens direct cineradiography becomes a much "faster" technique and can be applied to much larger and denser subjects. The size of the film frame may be anywhere from 5 by 5 in. to 12 by 15 in., the latter size being large enough to include an adult chest. When properly exposed, the so-called screen-films are recognized models of radiographic quality and would appear at first glance to be an ideal, if rather expensive, medium for making x-ray motion pictures of human subjects. Unfortunately it is not easy to impart rapid intermittent motion to large strips of film. Machines have been designed with the hope of making 12 or 16 pictures/sec, but few, if any, of them can be counted on to function at more than 4 or 5 pictures/sec without frequent breakdowns.[4] The necessity for sandwiching each frame of film closely between fragile screens at the instant of exposure makes the problem doubly difficult. Both film and screens pick up multiple scratches, dust and fragments collect at the aperture, and, worst of all, poor contact between screens and film results in grossly unsharp pictures.

The most successful attempts at full-scale cineradiography at true motion picture speeds have been made on continuously moving 15-in roll film exposed to extremely brief pulses of radiation. The single-coated film passes over an idle roller surfaced with a low-lag phosphor, the film being thus exposed in contact with what amounts to a single intensifying screen. With an experimental condenser discharge apparatus, as many as 100 exposures/sec have been made in this way.

As a rule, however, the motion studies made by method 2 are not true x-ray motion pictures, but simply rapid serial x-rays exposed at from 1 to 5 pictures/sec. Rapid serial x-rays have been much in demand in the past few years for making contrast studies of various parts of the circulatory system. The negatives are read as stills, although it is perfectly possible to copy them in sequence on motion picture film, and by repeating each negative frame three or four times on the print, to turn out a rather jerky motion picture.[5]

Cinefluorography

The great majority of true x-ray motion pictures are made by method 3, generally known as cinefluorography or indirect cineradiography. Here we have an economical and flexible technique for examining subjects of medium and large size at camera speeds up to 120 frames/sec. The faults of the method are, first, a less favorable exposure factor

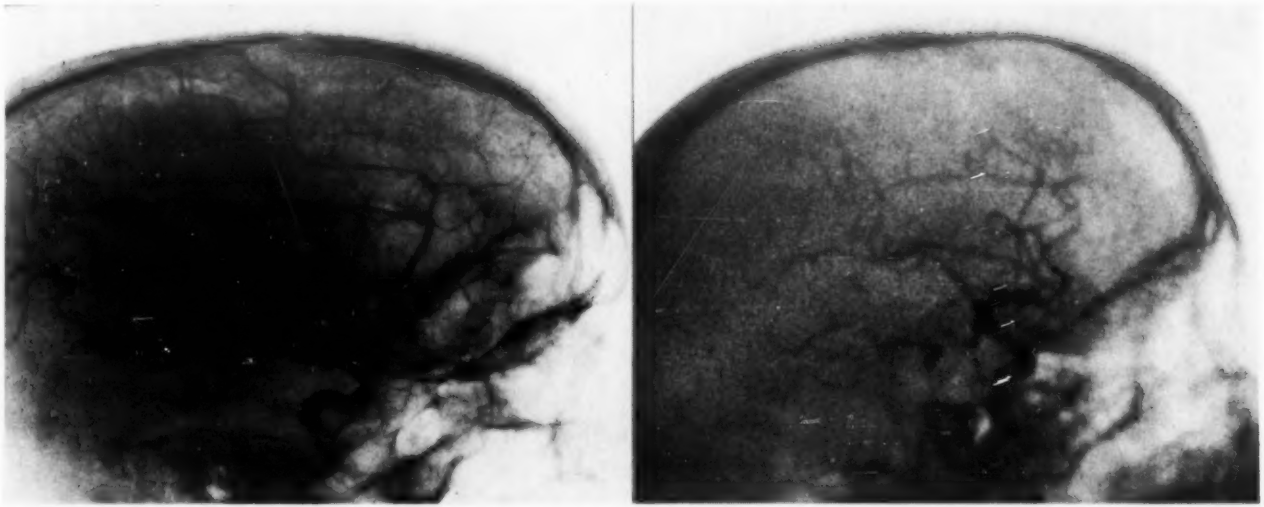

Fig. 1. Contrast studies of the cerebral circulation: left, contact print of a full-scale screen-film; right, enlarged 35mm frame from a 5-sec cinefluorographic record made with an f/0.85 lens and Patterson E2 screen at 60 frames/sec. Many of the smaller vessels which can be plainly seen on the full-scale film are only faintly perceptible on the 35mm film.

than that of direct cineradiography with screens, and second, a considerably greater degree of inherent unsharpness, as can be seen from the comparative figures given in Table I. It must also

Table I. Exposure and Unsharpness* Characteristics of X-ray Motion Picture Techniques

Method	Relative exposure requirement	Unsharpness* or blur, mm
1. Direct cineradiography (without screens)	25.0	0.05
2. Direct cineradiography (medium speed screens). . 12 by 16 in. E2 screen, *f*/0.85 lens, ortho film	1.0 2.0	0.3 6.0
3. 35mm cinefluorography 10 by 13 in. E2 screen, *f*/1.5 lens, ortho film	8.0	3.0
4½ by 6 in. D screen, *f*/1.5 lens, ortho film	16.0	1.5

* The unsharpness values listed above are offered as rough estimates and may contain a fairly large error. It is particularly difficult to give a satisfactory overall unsharpness value for the 35mm frame because of the wide difference between lens performance at the edge and in the center. For a constructive criticism of traditional sharpness and resolution measurements, see the recent paper by Higgins and Jones.[6]

be admitted that the single-coated motion picture film is inferior in contrast to double-coated screen-film. About the only remedy for this condition is the frequent use of a stationary grid to increase contrast by reducing scatter.

If sufficient radiation could be brought to bear, it would no doubt be possible to make 35mm cinefluorographic records displaying nearly as much subject detail as 35mm reduction prints from full-scale screen-films. There is, however, an upper limit to the amount of continuous or near-continuous radiation that can be provided by the x-ray machine, and this limit must be further reduced when dealing with human subjects. Subject thickness, camera speed and length of examination in seconds must all be taken into account in budgeting permissible radiation, often leaving little room for the niceties of good copying. The desirably sharp tungstate intensifying screen, to which routine screen-films owe much of their excellent definition, is replaced in cinefluorography of adult human subjects by a faster, less sharp screen coated with relatively coarse crystals of zinc cadmium sulfide. Then the blurred image formed on the unsharp screen is copied, blurs and all, by an ultrafast lens (definitely not a process lens) which in turn contributes additional blur and flare of its own.

As an illustration of what happens to fine subject detail under these extreme conditions we have reproduced side by side in Fig. 1 a full-scale screen-film and an enlarged 35mm frame taken from a cinefluorographic record. In this particular case the improvement of 35mm definition, which could have been obtained by using a slower, better-corrected lens or a slower, sharper screen, was sacrificed in favor of a relatively high camera speed. Figure 2 shows the improvement of definition which results from using a sharp screen in close-up views. Curiously enough we have been unable to obtain any appreciable increase in sharpness by substituting a finer-grain film for the fast green-sensitive ortho film commonly used in cinefluorography.

The *f*/0.85 lens referred to in Table I is the 55-mm Zeiss R-Biotar originally designed for 16mm film, but used, for want of anything better, on several 35mm cinefluorographic units including our own (Fig. 3). With this lens at full aperture, definition in the corners of the 35mm frame is frankly ter-

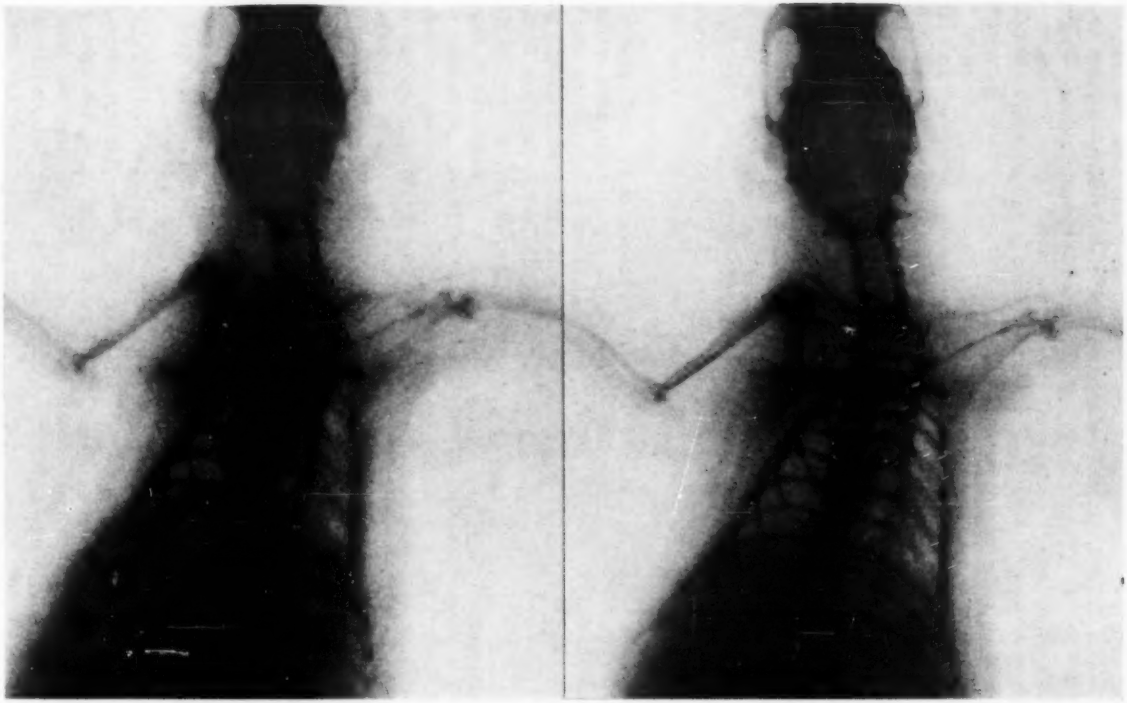

Fig. 2. Enlarged 35mm views of a rat: left, made with E2 screen; right, made with medium speed intensifying screen. Same lens and film were used for both. The right required 5 times as much exposure as the left.

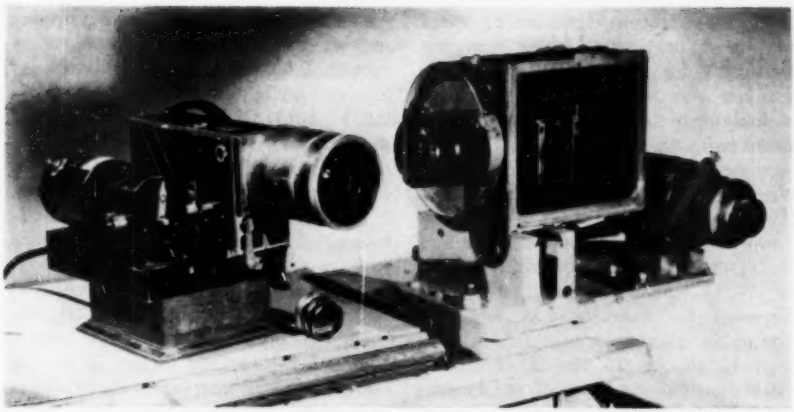

Fig. 3. Left, Kodak f/0.81 43-mm focal length lens mounted on Cine Kodak Special. A popular f/1.5 lens is shown below for comparison. Right, Zeiss R-Biotar f/0.85 55-mm focal length lens mounted on 35mm camera.

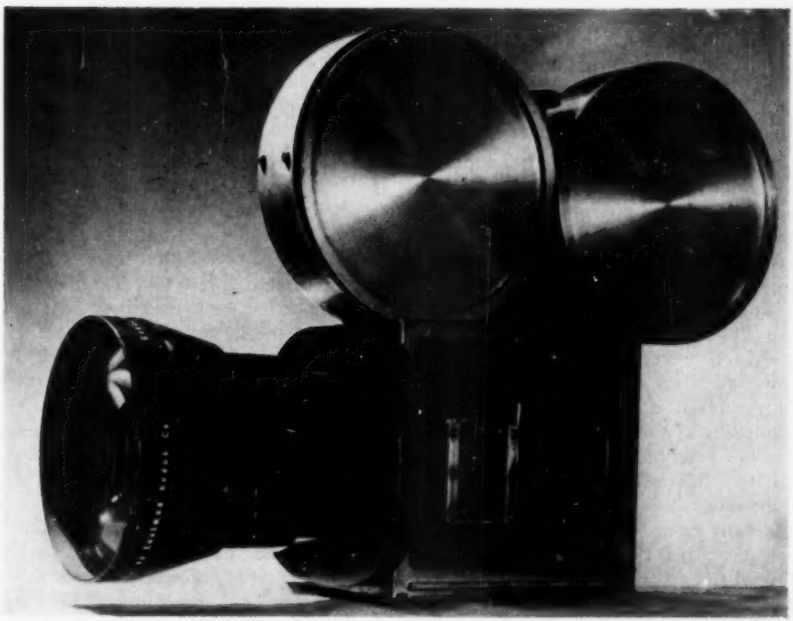

Fig. 4. New Kodak f/0.75 Fluro Ektar Lens designed for cinefluorography at a magnification of 1:16 (U.S. Patent 2,604,013).

rible. The recent announcement of two new refracting lenses designed specifically for 35mm cinefluorography promises better definition than can be had from the 55-mm R-Biotar, together with an increase rather than a decrease of speed. The lenses are the Wray 65-mm *f*/0.71 and the Kodak 110-mm Fluro Ektar *f*/0.75 (Fig. 4). Constructional details of the latter lens are described in the appended article by W. E. Schade. Both lenses are corrected for magnification of 1:16, that is, for a screen area a little smaller than 12 in. by 16 in. They should more than fill the place of the longer-focus Leitz and Zeiss *f*/0.85 lenses, manufactured at one time for 35mm cinefluorography, but unobtainable since 1940.

X-ray Motion Pictures by Kinescope Recording

The fourth method of making x-ray motion pictures has emerged as a by-product of recent experiments in fluoroscopic screen intensification. Of the various image tubes and other devices which have been developed for this purpose the only one at present adaptable to motion picture work appears to be the Johns Hopkins apparatus demonstrated by Morgan[7] in 1950. In Morgan's intensifier the fluoroscopic image is picked up by a television camera fitted with an *f*/0.7 Schmidt optical system of the "folded" type sometimes seen in television receivers. The reason for using such an extremely fast objective at the input end of the television apparatus is, of course, to make the most of the low brightness conditions prevailing on the fluorescent screen at average fluoroscopic x-ray intensities. It is now generally agreed that during fluoroscopy the near point on the subject's skin should not receive more than 10 r/min, a dosage rate frequently reduced to 3 r/min or less by increasing filtration of the x-ray beam and using higher peak voltage across the x-ray tube. At these comparatively low intensities the brightness of the fluoroscopic image rarely exceeds 0.03 ft-mL (foot-millilamberts) in the highlights, and may fall below 0.001 ft-mL in the shadows. That such an image can be picked up at all indicates the remarkable sensitivity of the image orthicon tube.

As it appears on the kinescope, the intensified image of the subject is said to have an average brightness of about 3 ft-mL, and is therefore, according to Morgan, from 300 to 3000 times brighter than the original fluoroscopic image. Like other kinescope images it can be copied at 30 frames/sec without resort to high-contrast film or lenses of aperture greater than *f*/1.5.

By way of demonstrating the motion picture possibilities of his intensifier, Morgan has made a kinescope recording of a barium enema examination of a child of 7, covering about 3 min of action,[7] during which time the subject is said to have received a total skin dose of only 20 r. If it were attempted to record a similar examination by routine cinefluorography (*f*/0.85 lens, E2 screen, stationary grid to reduce scatter, camera speed of 30 frames/sec), the total dose of 20 r would be reached in about 10 sec; in other words, only about 1/18 of the 3-min examination could be recorded. Of course, by reducing camera speed to 7.5 frames/sec (and repeating each negative frame on the print) the 10 sec of recorded action could be stretched to 40. Indeed, it would be possible by substituting the Fluro Ektar *f*/0.75 lens for the *f*/0.85 R-Biotar to prolong the take to 50 sec, but even so a more than three-fold advantage would remain with the kinescope record.

As can be imagined from the number of glass and electron optical stages involved in x-ray kinescope recording, the motion picture films made by method 4 are not at present satisfactory from the point of view of detail. To what extent this condition can be im-

proved remains to be seen. Certainly there is enough demand for better fluoroscopy, not to mention better image tubes and better television, to insure that the problem will not be neglected.

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Appendix: A New Kodak f/0.75 Fluro Ektar Lens*

By W. E. Schade

The new Kodak Fluro Ektar lens, $f/0.75$ of focal length 110 mm designed for 35mm cinefluorography at a magnification of 1:16, can be described as an extended modification of the classical example of simplicity, the Cooke triplet, to which a negative field-flattening element located near the focal plane has been added. Alternatively, the system could be regarded as a modified Cooke triplet to which a telephoto system has been attached.

However, since simplicity and the application of a field-flattening element have been the leading motives in the design of the lens, the following detailed explanations will pertain to the first description.

The $f/0.75$ Fluro Ektar lens consists of seven glass elements, two of which are made of the new high-index glasses developed and manufactured by Eastman Kodak Co. (Fig. 5).

The first two elements (1 and 2) are of collective power. These are followed by a hyperchromatic component of dispersive power. The negative element (3) of this component is made of a highly dispersing flint glass, whereas the other element (4) of this component consists of one of the new high-index glasses mentioned above. The properties of these two glasses, namely, nearly equal high indices of refraction for the D line, but widely differing dispersions, have made it possible to simplify the achromatization of the new lens.

Elements 5 and 6 are again of collective power, element 6 being made of one of the new high-index glasses.

The arrangement of these six elements, as shown in Fig. 5 produces a focal length of 106.4 mm and the marginal ray emerges at an aperture of $f/0.64$.

Finally, the field-flattening element (7) of dispersive power, located near the focal plane, then extends the focal length to 110 mm and reduces the aperture to $f/0.75$ as required.

The results of this relatively simple design are such that the lens will render

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The Appendix was contributed in June 1952 by W. E. Schade, Hawk-Eye Works, Eastman Kodak Company, Rochester, N. Y.

* U.S. Patent, 2,604,013, Aug. 8, 1951.

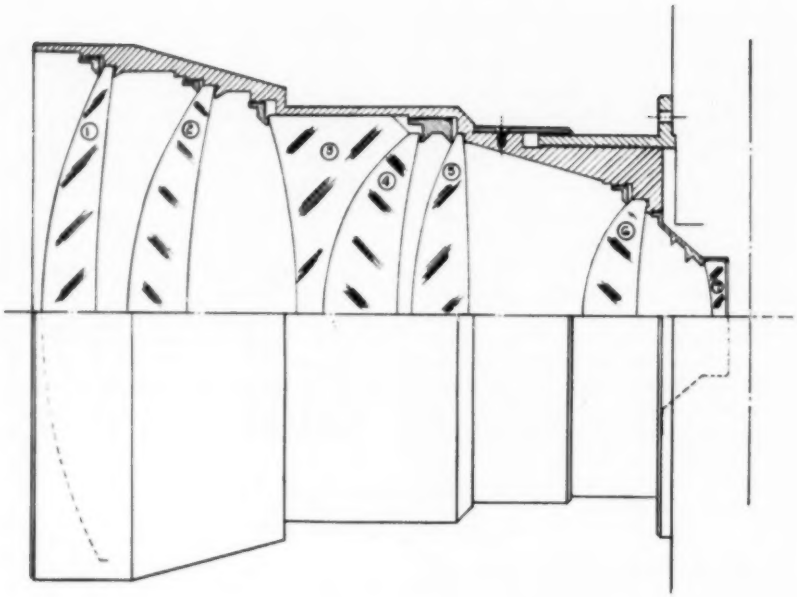

Fig. 5. Cross section of Kodak f/0.75 Fluro Ektar Lens of 110-mm focal length designed for 35mm cinefluorography (U. S. Patent 2,604,013).

highly satisfactory performance in many applications. The spherical aberrations have been reduced to an extreme minimum. Astigmatism and curvature of field are practically eliminated and the distortion (barrel) is negligible. The color corrections, longitudinal as well as lateral, are also fulfilled.

The dimensions of the system at a magnification of 1:16 are as follows:

Distance from screen to image plane	2023.1 mm
Object distance (from screen to first surface of lens	1807.8 mm
Image distance (from last surface to image plane)	7.3 mm
Length of lens (from first to last surface)	208.0 mm
Diameter of front aperture	143.2 mm

Since preliminary tests have proved the exceptionally satisfactory performance of the lens, it is anticipated many applications for it will be found in other fields.

A Precision Color Temperature Meter for Tungsten Illumination

By G. H. DAWSON, D. E. GRANT and H. F. OTT

A precision color temperature meter utilizing red and blue filters is described. A special logarithmic diaphragm largely eliminates undesirable effects of nonuniform response over the cell area and aids accurate setting of the red filter standard at high intensities.

For most visual or photographic purposes extremely accurate measurements of color temperature are not necessary. In the film industry, however, color films must be evaluated carefully to determine specifications which will, under proper conditions of exposure and processing, result in uniformly good color balance. Consequently, to remove test variability as much as possible, it is necessary to know and control within relatively close limits the color temperature of the tungsten lamps. A red–blue ratio is used as an index of color temperature since the radiation from a tungsten lamp follows closely the spectral energy distribution of a blackbody.

It was found that the variability within available meters was greater than the allowable tolerances of the tungsten source itself for testing purposes. Such a relatively high instrument variability would not assure a sufficiently reliable determination of color temperature.

Variability in most commercially available meters can be attributed to:

1. Differential diffusion of blue and red light and vignetting. These errors are most serious when the light is off axis or when an extended source is used.
2. Nonuniformities in response from one area to another of the cell, giving different effective color temperature readings at different intensities of illumination.
3. Difficulties in adjusting the instrument to the red filter standard at high intensities where the aperture over the cell is small and its area is changing rapidly when a direct linear diaphragm is used.
4. A trigger arrangement for shifting filters which moves the entire instrument when actuated.

Description

An improved color temperature meter, Fig. 1, utilizing red and blue filters has been designed by the authors to give the needed precision. Most important to

A contribution submitted July 21, 1952, by G. E. Dawson, D. E. Grant and H. F. Ott, Color Control Div., Eastman Kodak Co., Rochester 4, N.Y.

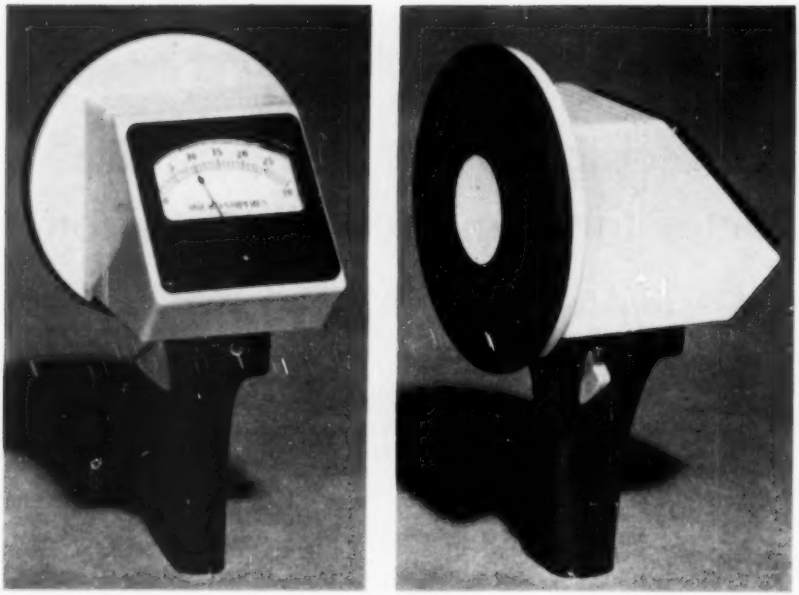

Fig. 1. Color Temperature Meter.

the increased precision is a specially designed diaphragm which allows incident light to be distributed over the cell surface at either high or low intensity.

The essential elements of the instrument, labeled to correspond to Fig. 2, are:

a. The diffuser
c. The special diaphragm
b, d. Filters
f. Trigger arrangement for switching filters
e. Photronic cell
i. Meter
g, h. Handle, including tripod socket

In use, the color temperature meter is pointed directly at the source to be measured and the diaphragm ring rotated until a standard reading is obtained on the microammeter through the red filter. The trigger is then depressed and a second reading is obtained through the blue filter. The color temperature of the source can then be read from a calibration curve. A scale could be inscribed on the microammeter reading directly in color temperature.

Diffuser, Cell and Meter

To keep the angular acceptance large, as well as to maintain accuracy of the instrument, an opal diffuser was put at the extreme front of the instrument. The metal parts, other than the diaphragm, were arranged so they could cause no shadowing of the cell. In addition, the diffuser-to-cell distance was made as small as possible. The diffuser chosen was an opalized cellulose acetate on glass support. To remove any effects of the blue–red diffusion differential of the opalized glass, a pale blue filter was placed between the diffuser and the diaphragm. Areas of the filter are cut away so that it gives maximum compensation when the dia-

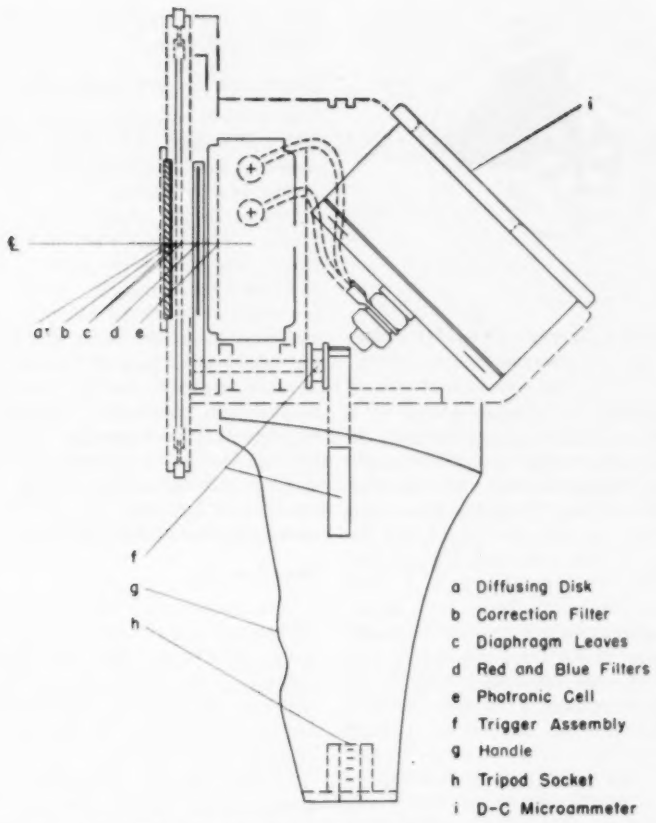

Fig. 2. Schematic side view of Color Temperature Meter.

phragm openings are large, but none when they are small.

The cell used in the instrument is a Type 3RR Weston Photronic Cell especially selected for low fatigue at both ends of the visual spectrum. The meter is Model 731 Weston 0 to 30 microammeter.

Diaphragm

The special diaphragm (Fig. 3) utilizes six leaves (a), three on each side of a thin center plate (b) which by rotation causes the leaves to move over the aperture or away from it. The leaves and actuating disk are between two outer plates. These plates support the pins on which the pivot ends of the diaphragm leaves can rotate. The diaphragm leaves have long, narrow tongues which at full open position extend across the circular diaphragm opening dividing it into six pie-shaped openings. Since the support pins for the leaves are spaced at 60° intervals alternately in one support plate then the other, the tongue of one leaf at full open aperture overlays the tongue of a leaf on the opposite side of the actuator.

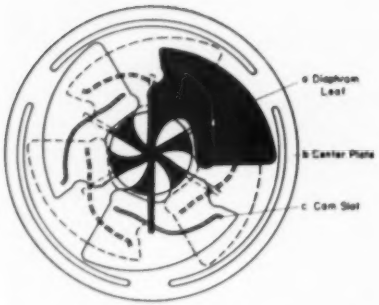

Fig. 3. Color Temperature Meter diaphragm.

The means of moving a leaf is a headed pin through a cam slot (c) in the diaphragm leaf into the center actuating member. As this member is rotated to close the diaphragm, each leaf moves inward, rotating about its support pin, the rate being controlled by the cam slots which are cut so that the logarithm of the open area of the diaphragm is proportional to the angle of rotation of the actuating ring. The logarithmic-type diaphragm ring facilitates accurate setting of the constant red filter reading regardless of light intensity. The leaves are so shaped that the pie-shaped openings first narrow abruptly as the diaphragm is closed, then gradually change shape to form six equally-spaced diminishing cat-eyes. The undesirable effects of nonuniform response over the cell area are thus largely eliminated.

Filters and Trigger Mechanism

The filters used were Kodak Wratten Nos. 38A and 29. These were so mounted that a thumb-actuated trigger mechanism replaced the red filter normally in the beam with the blue filter. The thumb-actuated trigger causes less instrument motion than a finger-actuated trigger. The handle, in the side of which the trigger is located, is shaped to fit the hand and is under the center of gravity of the instrument. It also includes a tripod socket for critical measurements. Although the instrument is accurate with illumination off axis, its sensitivity to intensity variations is still sufficiently critical so that care must be exercised to move the instrument as little as possible.

Precision

The color temperature meter was calibrated against 1000- and 1500-w lamps at 200 to 1000 ft-c. The precision of the instrument as normally used is ± 5 K. As the angle of illumination increases from 30° off axis to the angle at which a reading can no longer be obtained, the precision decreases gradually to ± 10 K. The accuracy is dependent chiefly upon the validity of the calibrations of the lamps used as standards.

Comparison of Recording Processes

By JOHN G. FRAYNE

The three common forms of sound recording may be classed as mechanical (disk), photographic and magnetic. All three methods are in common use today and each is employed in a field for which it appears to be peculiarly fitted. The purpose of this article is to examine briefly the factors which determine the fidelity of each method. By fidelity we mean how true the tonal range can be reproduced, the amount and nature of harmonic distortion present, the signal-to-noise ratio possible with each method, and the amount of wow or flutter that may be expected under average conditions of reproduction for each recording process.

Disk Recording

Although there are other methods of mechanical recording, such as embossing, we shall confine our discussions on mechanical recording in this article to the well-known circular flat disk method. This type of recording remains the most popular form for home entertainment and is widely used in transcription radio programs. One characteristic that differentiates disk recording from the other methods is the comparatively higher mass of the moving parts involved in making and reproducing the record. The disk material must actually be cut with a stylus having a high degree of stiffness and a comparatively high mass. Likewise on reproduction, disk recording involves the movement of a reproducing stylus which in itself must have considerable stiffness and mass. In disk recording, the resonant frequency of the recorder is usually considerably below the highest recorded frequencies. Since this necessitates recording through the resonant range of the recorder, a high degree of damping must be employed to remove the resulting resonant peak. This damping, whether supplied by mechanical means or electromagnetically through some sort of feedback system, results in a velocity of the recording stylus which is constant and independent of the frequency for a constant applied force. This type of recording is known as constant velocity and with the addition of pre-emphasis in the recording circuit is widely used in cutting present-day high-quality records.

Since the amplitude of the cut for a constant applied force is inversely proportional to the frequency in a constant velocity recorder, it is customary to record the lower frequencies or longer

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A technical editorial by John G. Frayne, Westrex Corp., 6601 Romaine St., Los Angeles 38, Calif. Reprinted by permission of the Editor of The Institute of Radio Engineers, from *Transactions of the IRE, Professional Group on Audio, PGA 6:* Mar. 1952, and *PGA 7:* May 1952.

wavelengths on a more nearly constant amplitude basis. This limits the amplitude of the cut at the lower frequencies. The frequency at which the changeover is made is usually referred to as the crossover point. In cheaper recorders, this presents no problem, but in the higher-quality feedback-type recorders, this has to be done by appropriate recording equalization. With the best type of feedback cutters, good records may be recorded out to 12–15 kc, whereas on the cheaper types 5 or 6 kc is a desirable upper limit. When a constant velocity record is reproduced with a variable reluctance type of reproducer, a constant voltage results. For those parts of the spectrum cut at constant amplitude, reproducing equalization complementary to that used in recording must be used.

Like all recording media, disk recording is subject to its own peculiar types of distortion. One of the most common forms of disk distortion is brought about by the fact that a sinusoidal wave cut into the record must be tracked in reproduction by a stylus of finite radius of curvature. It is obvious that at short wavelengths it is impossible under such conditions to reproduce a true sinusoidal response. Instead, a series of poids result which, in the case of the more common lateral type of disk recording, produce odd-order harmonic distortions. Since the wavelength for any given frequency diminishes as the groove diameter of the disk is reduced, such distortion increases rapidly with diminishing diameter for any given impressed frequency. This has been studied in detail by Pierce and Hunt and they show, for example, that in 33⅓-rpm records, distortion at 5000 cycles may amount to as much as 30% for an 8-in. diameter, dropping to as low as 2% for a 16-in. diameter. Similarly for 78-rpm records for the same frequency, distortion may amount to 20% for a 4-in. diameter and drop to approximately 1% for a 12-in. diameter. It is this factor which limits the effective inner diameter on 33⅓-rpm microgroove records to 5 in. and on 45 rpm to 3¾ in. Accompanying this increasing distortion as the groove diameter is reduced is a corresponding loss in high-frequency response. This may be corrected to a certain degree by introducing variable equalization in recording, increasing the high-frequency input to the cutter as the groove diameter is reduced. While this may correct for high-frequency response, it only adds to the distortion resulting at the higher inputs.

Another form of distortion in reproducing from disk records is known as tracking distortion. This is brought about by the fact that since the reproducer is supported by a pivoted arm, the angle which the axis of the stylus makes with the groove is constantly changing as the reproducer moves across the record. This form of distortion is very complicated and results in the generation of both even and odd harmonics. This tracking error can be reduced to a minimum by proper design of the reproducing arm.

The commonly used expression "wow" to denote low-frequency speed variations in sound reproduction had its origin in the once-per-revolution speed variation (wow) of cheap disk turntables. At 78 rpm this corresponds to a frequency of 1.3 cycles/sec, a rate at which the ear is extraordinarily sensitive to pitch changes. This low-frequency rate is a difficult one to correct in a mechanical system without resort to very expensive and accurate drive systems which are completely beyond the range of the home pocketbook. The problem is further aggravated by the provision for three speeds in many turntables, each of which may call for somewhat different corrective mechanical filtering. In the professional field, the problem of wow has been largely overcome and flutter less than 0.1% may be attained.

Another factor which has limited high fidelity in disk reproduction has been the so-called needle scratch. This has been accented by the use of the older-type shellac records carrying an abrasive for grinding the steel reproducer needle to match the groove. This condition has been greatly improved in recent years by the adoption of improved pressing materials such as acetate or Vinylite and the wide adoption of permanent-type needles. For home use, a signal-to-noise ratio of the order of 40 db is probably adequate, but for professional use this should be improved to at least 50 db. A further improvement in signal-to-noise ratio is the recent adoption of the so-called hot stylus technique in recording. This method usually results in an improved signal-to-noise ratio especially at the inside area of the disk. Simultaneously, it appears to result in improved high-frequency response.

When one considers the mechanical nature of disk recording and reproduction and the fact that a plastic with its cold flow and general instability has to be employed, the resulting fidelity in modern disk recording may be considered a triumph of research in industrial design and manufacture. When one further takes note of the various processes which are followed in going from an original acetate cut record through the plating and stamping processes, one is further impressed at the really excellent job that can be done in modern disk recording.

Photographic Recording

Under ideal conditions of recording, processing and reproduction, modern photographic recording offers a medium of high-fidelity sound reproduction the equal, if not superior, to that of any other method. Two well-known methods — variable-density and variable-area — are in wide use in photographic recording. With accurate control of film processing, extremely high fidelity records may be obtained for both variable-density and variable-area methods. In the professional 35mm field, such controls are successfully used with a resulting high-quality product. In the lower-cost 16mm field, it is a matter of regret that much improvement is still awaited in this regard. Over the years since photographic recording was first introduced, there has been a vast improvement in the type of photographic emulsions suitable for both density and area recordings. Recording devices and light-modulating systems have been brought to a point of near perfection, and the general improvement in the electronic art has contributed to practically distortion-free film and reproducing systems.

A method of reducing background noise unique to photographic recording is the universal use of bias or noise-reduction recording in which the average transparency of the sound track varies with the envelope of the sound waveform. This results in a minimum of film grain noise and photocell hiss for the low-level passages and automatically permits a rise in these unwanted noises as the signal amplitude increases.

The most difficult problem to overcome in photographic recording has been the development of high-quality transport of the film past the point of optical translation. The earlier film recorders were subject to much wow and flutter with disturbing rates varying all the way from 1 cycle/sec to 96 cycles/sec, the latter corresponding to the sprocket-hole frequency of 35mm film. As a result of much research into the nature of flutter, improved designs of professional 35mm recorders and reproducers have been introduced in recent years which are remarkably free from flutter. Today, a photographic recorder with a total flutter content exceeding 0.1% would have difficulty finding any market. In 16mm photographic recording, due to the slower speed employed, it is more difficult to

secure equally good film movement. This is only too obvious in the reproduction of many 16mm sound tracks heard over television programs. As a consequence, high-quality 16mm film recorders should call for more careful design and construction than the more professional 35mm types. The contrary, however, has usually been the result, due to the poorer economic status of 16mm. The same comment holds even more true for 16mm reproducers. Instead of the sturdy professional-type 35mm theater reproducers, the 16mm field has until quite recently been content to use lightweight, portable, flimsily built 16mm reproducers to meet a highly competitive market condition. Recently, due to the wide use of 16mm film in television, there have appeared several professional 16mm reproducers which tend to overcome this difficulty.

At the standard speed of 18 in./sec for 35mm, the practical upper limit to frequency response is around 8–10 kc. This limit is the result of recording and printing high-frequency losses as well as the losses introduced by the use of a finite scanning slit in reproduction. This has been recognized by the motion picture industry in limiting frequency response of theater systems to approximately 8 kc. In the 16mm field where the film speed is only 40% that of 35mm, it is much more difficult to secure a wide frequency response. It is only by resort to considerable equalization in recording and reproducing that satisfactory response to 6 kc may be made. This inevitable shortcoming of 16mm recording results in the well-recognized "chesty" nature of the sound.

The limiting factor in the signal-to-noise ratio in film recording is the background noise produced by the graininess of the photographic image and also by the accumulated dirt and scratches on the film. This usually limits photographic tracks to a usable signal-to-noise ratio of around 40 db, although new tracks employing fine-grain films and noise-reduction techniques may give a value of at least 50 db.

Even though an excellent photographic track may be obtained from the film processing laboratory, the final result may be considerably affected by the reproducing mechanism. Flutter in the reproducer will produce results equally as disastrous as those from poorly made film recorders. Considerable distortion, especially in the variable-area system, may be encountered by nonuniformity of the scanning beam in the reproducer and even more seriously by failure to have the reproducing scanning beam in the correct azimuth. Other limitations in reproducing, especially in 16mm, are low-cost amplifier systems which do not have sufficient output capacity for the higher-level passages on the film and insufficient hum filtering which in many cases permits an audible 60-cycle reproduction from the loudspeaker. In the matter of loudspeakers, the photographic system probably fares better than either of the other two methods. There has been a vast improvement in loudspeakers in professional 35mm theaters. This cannot be said, however, for the speakers used in the lower-cost portable 16mm reproducing systems.

Magnetic Recording

In common with the other recording techniques discussed above, magnetic recording is also affected by uneven motion of the magnetic tape or film in the recorder and reproducer. The extreme flexibility of the standard $\frac{1}{4}$-in. tape aids considerably in simplifying the tape-pulling mechanism and it is possible to obtain considerable freedom from very low flutter rates with a relatively inexpensive drive. The common capstan-type drive usually introduces low-frequency flutter rates which, however, are considerably higher than those encountered in disk recording and are, therefore, not so objectionable to the ear. Magnetic recording, however, does

introduce a considerable amount of high-frequency flutter of a somewhat random nature which may be traced to the irregular motion of the tape or film over the magnetic head. Fortunately, these rates are sufficiently high so that their effect on the ear is negligible except at the higher audiofrequencies such as some of the higher overtones from string instruments. This irregular motion of the tape over the magnetic head also introduces considerable amplitude distortion which produces an effect almost indistinguishable from that of the high-frequency flutter. Thus, at the commonly accepted speed of 15 in./sec, both of the effects produce a very harsh quality if the sound spectrum is pushed up to the 15-kc limit.

Magnetic tape recording utilizing the high-frequency bias may be reproduced with a minimum of distortion which is generally lower than that in either disk or photographic recording. At the same time, a signal-to-noise ratio of 50 to 60 db may be obtained. This, however, calls in recording for a very high-quality, high-frequency bias oscillator with a second harmonic content about 60 db lower than the fundamental. The ratio of the high-frequency current to the maximum audio current must be of the order of 10 to 20. To achieve the low noise level and relative freedom from distortion, extreme care must be taken to insure that the magnetic head and associated shield do not acquire any permanent magnetism, as the d-c magnetic field thus produced acts in a manner directly analogous to the presence of second-order harmonic components in the high-frequency bias oscillator. One common result of these d-c fields is a pronounced rumble in reproduction. This same effect may also be traced to improperly erased tape. With the proper value of high-frequency bias for any given magnetic head and tape, the distortion above the so-called overload of the medium is mostly third-order harmonic components, the second-order being almost entirely absent. Experience has shown that considerable overload may be tolerated and this is generally attributed to the absence of the more unpleasant even-order harmonic components. A disturbing factor in $\frac{1}{4}$-in. tape is the presence of so-called "print-through" from layer to layer, resulting in what appears to the listener as an echo. This can be prevented by reducing peak amplitudes in the recording and may be prevented from becoming too serious by avoiding storage of recorded tape in excessive high-temperature locations or in the proximity of high magnetic or electrostatic fields.

The frequency response from magnetic film recorded at constant current input to the recording head increases at a 6 db per octave rate over a considerable portion of the audio spectrum. It then flattens off and begins a fairly sharp decline. This dropping off at the upper frequencies results from two causes — one, demagnetization in recording at the shorter wavelengths; and two, the scanning losses which are directly analogous to those found in film reproduction. For a 0.5-mil reproducing gap and speed of 15 in./sec, this fall-off in high-frequency response begins in the neighborhood of 2000 to 3000 cycles. It is customary to correct for the 6 db per octave slope by inserting a simple *RC* correcting network in the reproducing circuit, and a fairly flat response may be obtained down to approximately 100 cycles by this simple expedient. Below this point, irregularities in low-frequency response are frequently encountered, and more complicated means of equalization must be employed if these are to be smoothed out. To insure a wider, higher frequency response, equalization must be used and it is customary to do this partly in recording and partly in reproducing. As pointed out above, a tape speed of 15 in./sec in response may

be made flat out to approximately 15 kc without resort to excessive equalization.

One of the problems peculiar to magnetic recording is the care that must be taken to avoid excessive 60-cycle hum pickup in the reproducer. Since the common power-line frequency of 60 cycles may have a gain 20 to 30 db higher than say 1000 cycles in order to correct for the nonlinear frequency response referred to above, the pickup head and the input circuit, especially the input transformer of the preamplifier, must be well shielded to avoid pickup from ambient 60-cycle fields. Fortunately, the well-known ear characteristic for medium sound reproducing levels aids in reducing the effect of such a disturbing frequency. The ear's being at least 20 db less sensitive at this frequency than at a 1000-cycle tone means that an effective signal-to-noise ratio of 40 db at 60 cycles will be equivalent to a 60-db signal-to-noise ratio at the higher frequency.

In conclusion, we may note that all three media have their own particular factors that limit their fidelity. When all factors including economic are taken into consideration, the magnetic medium appears to offer the greatest possibility of high-quality sound reproduction with a minimum investment in recording and reproducing equipment. The re-use of the tape and the general simplicity of operation are other factors which seem to be responsible for the remarkably wide use of the magnetic medium in the very short period since its general introduction in this country.

A Building-Block Approach to Magnetic Recording Equipment Design

By KURT SINGER and J. L. PETTUS

The requirements of magnetic recording equipment for sound motion pictures have been found to vary greatly with different customers. In order to provide the necessary flexibility to meet these different requirements and to include various custom features, the functional units of a magnetic recording channel have been designed on separate rack-mounted panels which can be installed in varying arrangements in a standard amplifier rack. These include items for both single-track and three-track equipments, and film widths of 16mm, 17½mm and 35mm.

THE EQUIPMENT required for a sound recording plant varies widely depending on the type of recording, the size of the associated studio, and the magnitude of the plant operation. In this respect magnetic recording or reproducing equipment differs in considerable detail over its predecessor, photographic recording and reproducing equipment. In the latter case, certain facilities were necessarily reserved for photographic film handling. These included dark rooms, film magazines and lighttight enclosures in the recording facilities. In contrast, magnetic equipment offers some consolidation in plant layout as well as certain conveniences in operation.

Presented on October 18, 1951, at the Society's Convention at Hollywood, Calif., by Kurt Singer and J. L. Pettus, Radio Corporation of America, RCA Victor Div., Engineering Products Dept., 1560 N. Vine St., Hollywood 28, Calif.

The requirements of magnetic recording/reproducing equipment for sound motion pictures have been found to vary greatly with different installations. These requirements plus the fact that many studios will wish to install minimum equipment at the beginning and "grow" with the development of magnetic recording, led the authors to the conclusion that studio equipment should be made of carefully planned units so coordinated that they could be easily fitted together to provide almost any desired combination of equipment layout. This is essentially the "building block" idea which is today employed in many types of industrial apparatus. Thus, when expanding a system such as from a few magnetic recording channels to a more comprehensive system or from a single-track to a triple-track recorder/-reproducer, it is not necessary to add entirely new recorder mechanisms but rather to increase the number of compo-

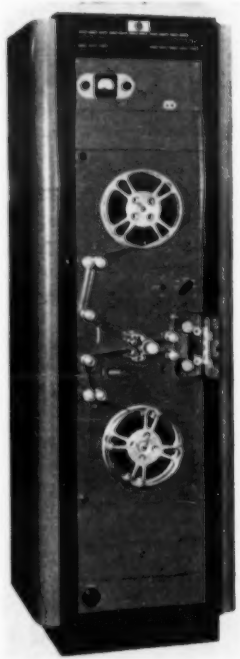

Fig. 1. Single-rack assembly, Type A equipment.

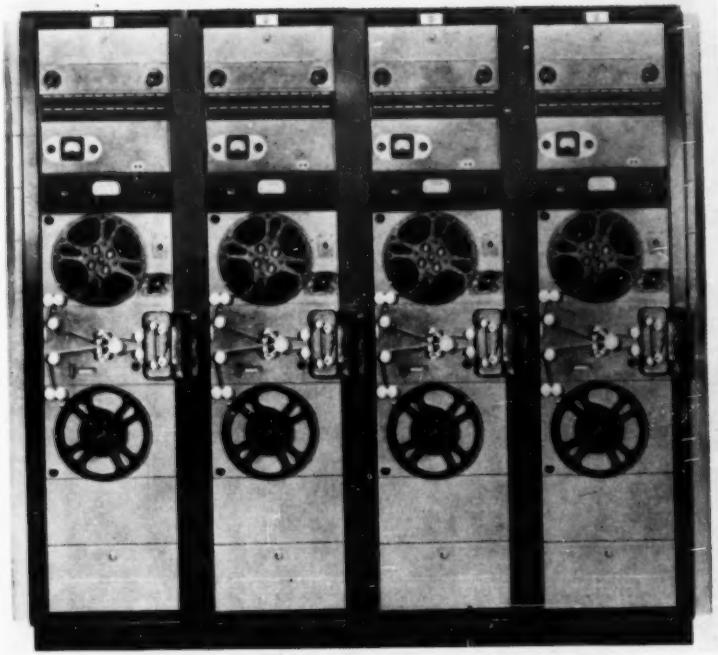

Fig. 2. Multiple-rack assembly, type A equipment.

Fig. 3. Single-rack assembly, Type B equipment.

nents as desired. Moreover, this is readily possible if all of the component assemblies have been designed to mount on a standard relay cabinet rack or equivalent having the industry standard multiple dimensioning. The three system layouts described in the following text have been chosen to illustrate the wide range of equipment combinations which are practical. For the most part, these are actually in use or are now being installed in several large motion picture studios.

Of the different equipment combinations to be described, types A and B utilize a single magnetic track while type C provides three sound tracks having all tracks recorded and/or reproduced simultaneously and positioned in accordance with Motion Picture Research Council proposed standards.[1]

Basic Mechanical Arrangement

There are several ways of arranging components in the vertical plane but these generally follow the rules of hand and eye levels for those items requiring the greatest amount of operation attention. An example of a single-track magnetic recorder/reproducer channel is shown in Fig. 1 and identified as RCA type PM-66 equipment. Here the extreme upper portion of the rack supports the bias oscillator/preamplifier followed by a film-feed assembly, a control panel, a film-drive mechanism, a film take-up assembly after which are located power supplies and other miscellaneous audio components. Figure 2 shows a number of these units assembled in line for a multiple-channel installation, yet with each unit being capable of independent operation.

Figure 3 shows a type B arrangement for application where it is desirable to reduce the vertical height of the mechanical components to a minimum. Here the controls have been relocated on the film-feed assembly to conserve space. As in the type A equipment, the audio components are located above and below the mechanical units and positioned as to their operating convenience.

Type C equipment is shown in Fig. 4 as an arrangement which provides a three-track magnetic recorder/reproducer channel and is identified as RCA type PM-63 equipment. Here it was necessary to assemble all audio components in two racks and all mechanical components in a third rack. All racks are tied together to form a single and complete unit assembly. Such an arrangement provides for maximum serviceability to all elements but occupies only minimum plant space. Here again many components as shown in Fig. 1 are used with only minor alteration to the film-drive mechanism for the number of magnetic-head assemblies employed.

Selection of component assemblies in practice follows the requirements and specifications for a given installation. To begin with, the width of the recording medium, the number of magnetic tracks per channel and the required film capacity determine the basic elements. In general, the width of the film does not alter the basic design except for the physical size of certain parts and the speed of the film-driving mechanism. This latter difference has been chiefly limited to the use of 16mm film operating at 36 fpm and 17½ or 35mm film operating at 90 fpm. However, in view of further economy in magnetic recording, the use of 17½mm film operating at 45 fpm for all original or production recording, is gaining favor in the industry. Magnetic recording equipment for 45 fpm operation was presented before this Society in a paper entitled "A Technical Solution to Magnetic Recording Cost Reduction."[2]

The number of magnetic tracks regardless of the width of the film has been primarily limited to the use of a single track on all widths for production recording and triple tracks on 35mm film in dub-

Fig. 4. Triple-track rack assembly, Type C equipment.

bing or re-recording operations. Of course, there are many possibilities of using a plurality of tracks on either of the other two film widths.

Description of Mechanical Components

A. Film Feed and Take-up Assemblies. A panel of approximately 15¾ in. high will accommodate a film capacity of 2000 ft. This size was chosen as being most satisfactory in the majority of installations. In the past, many recorder/reproducer designs have used a rather simple friction-type clutch as an integral part of the feed and take-up assemblies to tension or wind the film on the respective film reels. The applied tension between start and finish pay-out or take-up of a 2000-ft-roll of 35mm film wound on a 2-in. diameter core, was found to vary by a ratio of 1:8 under average operating conditions. Such a variation reflects an undesirable condition to the film-drive mechanism. Furthermore, the desire to incorporate rewinding from reel to reel as a feature on new equipment is well founded.

These two factors guided the design to make use of a torque-type motor to serve as a tensioning device having a nearly linear characteristic for both holdback and take-up as well as being suitable for a high-speed rewind. The first function was obtained by applying varying potential to the motor in proportion to the amount of film on the reel and phased for rotation opposite that of the film pay-out. This provided an ideal holdback system. Similarly, it also provides an ideal take-up system except that rotation of the torque motor must agree with the direction of film winding and have somewhat greater torque. The third function

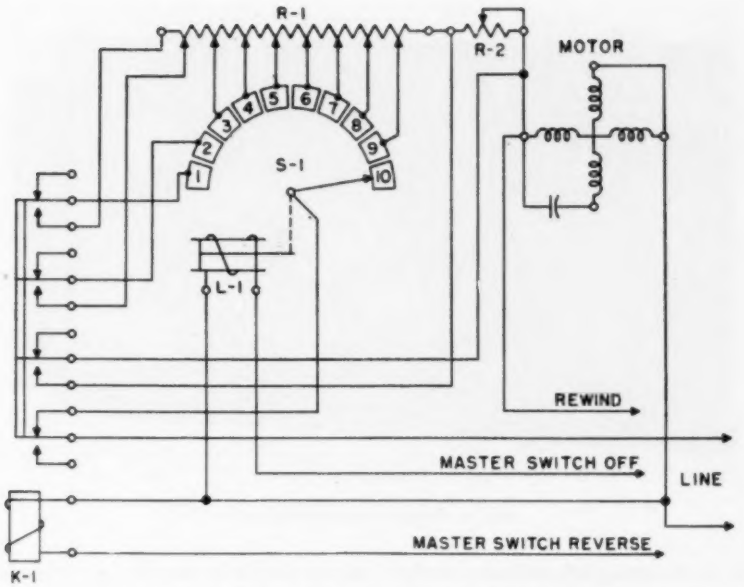

Fig. 5. Schematic of torque motor voltage controller.

as a rewind was obtained by using the motor at its rated output as a propulsion device. The electrical elements of this assembly are shown schematically in Fig. 5. From this, it will be noted that the use of a variable series resistance (R-1) in one leg of a single-phase motor, serves to vary the motor torque for either holdback tension or forward torque for take-up. The resistor (R-1) is varied by a commutator (S-1) by means of a follower arm in contact with the periphery of the film roll. Additionally, a relay (K-1) is used to vary the overall torque curve when the motor is functioning for a take-up instead of a holdback as in the case of reverse operation. This relay is normal in the holdback function and energized by the master control switch for the reverse or take-up function. As shown in Fig. 5, the commutator switch (S-1) is in its initial position at the maximum film roll diameter thus placing the least amount of R-1 in series with a second resistor (R-2) and this combination being seen by one leg of the torque motor. As the commutator switch progresses with a decrease in film roll diameter, sections of R-1 are automatically added, proportionally reducing the motor torque. As the last two steps are reached, R-1 is opened allowing only the inherent load of the motor-drive assembly to serve as friction in the holdback function, these two steps being at diameters less than 5 in. When functioning as a take-up device, relay K-1 becomes energized and shorts out R-2 to increase the overall torque range. Additionally, steps 1 and 2 of S-1 are seen by R-1, thus giving a potential to the motor at the minimum or starting diameter of the take-up roll. Controlling the torque of each motor by the described method produced a film tension characteristic constant within 2 oz throughout the length of a 2000-ft reel using a 2-in. OD core.

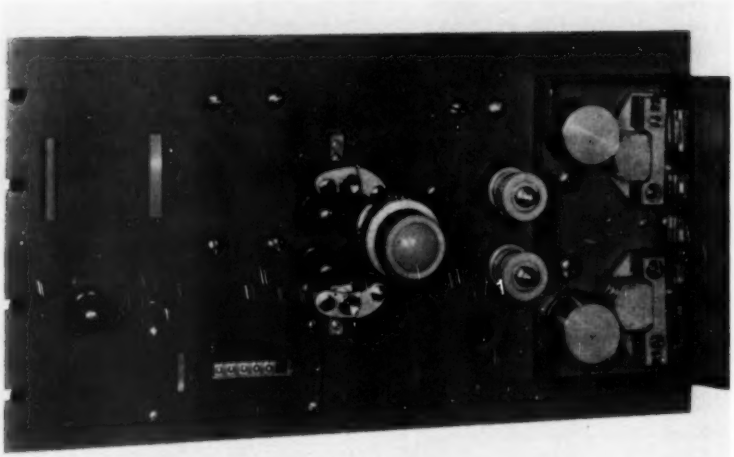

Fig. 6. Film-drive mechanism.

As an operating convenience, the follower arm is automatically retracted from the film reel by means of a solenoid energized through the master control switch when positioned at OFF. Upon setting the master switch for the desired operation of the film drive, the follower arm is released and allowed to seek the periphery of the film roll. Thus, a predetermined potential to the torque motor is automatically established.

B. Control Panel Assembly. As shown in Fig. 1, controls for the film-drive mechanism, as well as for rewinding, are mounted on a separate panel. An exception to this arrangement was shown in Fig. 3 where these controls were placed on the film-feed assembly in order to conserve rack space for a particular installation. In general, the separate panel allows the use of larger film reels and gives several operating as well as manufacturing conveniences. In the latter respect, the associated film-drive mechanism may use any of the industry standard motors including the combination synchronous/interlock type. The use of a separate control panel therefore permits a variety of electrical combinations to suit the associated motor systems without alteration of the other electrical circuits. Figure 1 shows the master switch designated for operation of a combination synchronous/interlock film-drive mechanism motor. This switch is divided into eight positions in order to give independent switching for the respective sections of the motor. It is also seen that on either side of the OFF position for synchronous motor control, there appears a READY position which permits energizing the feed and take-up motors before completing the circuit to the film-drive mechanism motor. Thus, the torque motors, being pre-energized ahead of the actual rolling of the overall mechanism, remove all slack in the film path and permit the feed and take-up reels to follow the acceleration or deceleration of the film-drive mechanism motor. READY positions for interlock operation are not required since the torque motors are energized on the LOCKING cycle of the interlock motor system.

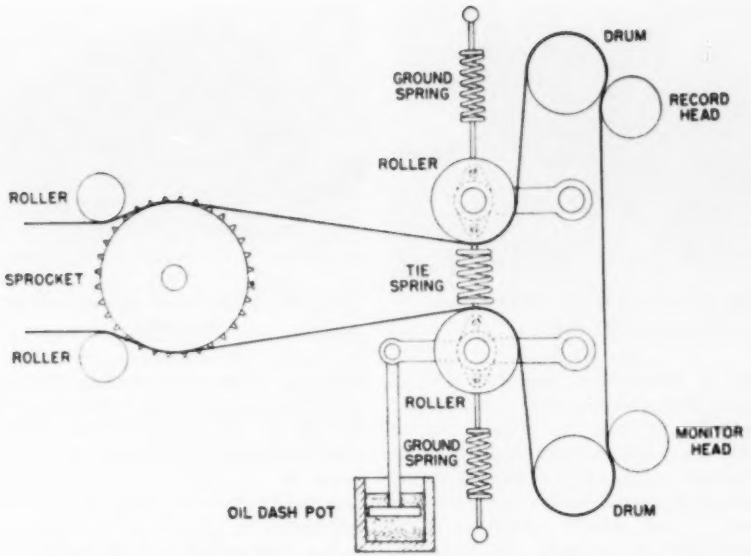

Fig. 7. Schematic of film-drive mechanism mechanical filter assembly.

A key switch, which controls the respective torque motors through relays, allows film to be rewound from reel to reel with the direction established by the position of the key. For instance, if rewinding is to be from the lower to the upper reel, positioning the rewind key switch in the UP position connects the upper motor for maximum torque and likewise connects the lower motor for reduced and reversed torque in order to establish tension in the film. Rewinding in the reverse position follows a similar procedure.

C. Film-Drive Mechanism. This assembly might well be considered a basic item in the building-block plan for a magnetic recorder and/or reproducer unit. The foregoing discussion is therefore primarily concerned with the accessory items required by the film-drive mechanism but varied to suit a particular installation. Figure 6 shows the components of the drive unit. The base of this assembly consists of a cast aluminum alloy plate occupying 10½ in. of vertical rack space. Attached to this plate are a drive motor, a mechanical filter system, magnetic heads — either single- or triple-type — a footage counter and several film-guide rollers, etc. The drive motor is worthy of mention to the extent that an integral part of it is a reduction-gear unit whose output shaft is suitable for direct coupling to the film-drive sprocket. The speed reduction from motor to sprocket is obtained by single-series helical gearing. Ratios varying between 10:1 and 125:9 to suit the many permissible different types of motors and film speeds are used. Since the drive motor does not power the take-up system, its frame size has been reduced to a minimum while maintaining a power output in the order of 3:1 over that of the actual torque requirement. This motor unit develops approximately 20 mechanical watts when designed as a three-phase motor and somewhat more when designed as an interlock-type motor. The use of permanently lubricated bearings together

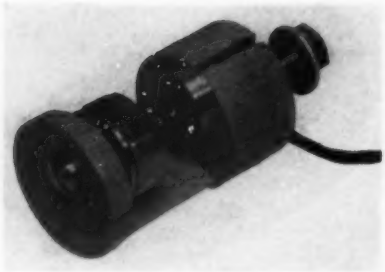

Fig. 8A. Single-track magnetic-head assembly.

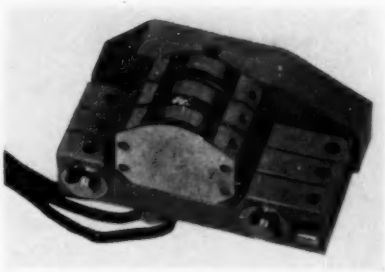

Fig. 8B. Triple-track magnetic-head assembly.

with a grease-filled gearbox reduces maintenance and operating attention to a minimum.

The mechanical filter system, schematically shown in Fig. 7, consists of two drum-shaft assemblies having identical flywheels as inertia elements. Both drums are film-pulled. Two sprung tensioning rollers with damping applied to one tension roller comprise the other elements of the filter system, the damping being obtained by means of a fluid silicone oil type dashpot connected to one roller arm by a mechanical linkage. The entire system is near critically damped with a resonant frequency of approximately $1\frac{1}{2}$ cycles/sec.

Magnetic head assemblies may be, as previously mentioned, selected to suit the particular requirements of the installation, i.e., single- or triple-type tracks. Either assembly is interchangeable with respect to the film-drive unit. The single-track type is shown in Fig. 8A. Here it is seen that the head is mounted by means of a one-piece holder having a ball-and-socket type of anchorage which allows longitudinal, lateral and transverse adjustments of the head with respect to the recording medium.[3] The use of a shoe which contacts the film on the edge opposite the sound track, and which is of a width equal to the magnetic track, has been found advantageous. This shoe maintains the plane of the film across the magnetic head as well as distributing the unit area pressure to minimize head wear. An interesting note is that the use of a hardened stainless steel shoe was found most practical for obtaining a wear characteristic nearly equal to that of the mu-metal used in the magnetic-head, laminated pole pieces.

Also seen in Fig. 8B, the triple-track assembly employs three heads arranged in line and positioned in accordance with the Motion Picture Research Council's proposed standards for sound-track positions.[1] This assembly, while obviously more complex than that of the single-track magnetic-head unit, provides the same individual head adjustments although accomplished in a somewhat different manner. The lateral or azimuth adjustment of each head is obtained by pivoting the head-mounting yoke on a supporting arm. The transverse adjustment is obtained by pivoting the individual arms on a lateral supporting shaft, and the longitudinal adjustment is obtained by moving the entire head assembly with respect to the mounting base.[3] No supporting shoe is required by the triple-track assembly since the heads themselves contact the film uniformly across its width. The construction of the magnetic head proper, used in both single- and triple-track units, follows that described by Rettinger.[4]

When the film-drive mechanism is to serve as a recorder with monitoring, two identical head assemblies are employed,

each assembly being positioned near the respective drum-shaft assemblies. These positions were chosen after extensive investigation for optimum performance in both constancy of motion and uniform output from the recording medium. A more comprehensive discussion of this investigation was presented before the Society in a paper entitled "Twin-Drum Film-Drive Filter System for Magnetic Recorder-Reproducer."[5]

Among other features of the film-drive mechanism believed to be of interest, is one commonly called the free-wheeling sprocket. Specifically it is a means of disengaging the film sprocket from its drive source and is considered essential to any reproducer using an interlock motor system. With this facility, synchronization marks may be readily brought to a reference position without disturbing the interlock of the driving motor. Such an assembly is shown in Fig. 9 in an expanded view. Essentially, this consists of a multi-jaw coupling which may be manually disengaged to free the film sprocket. It will be seen that one-half of the multi-jaw coupling is fixed to the sprocket drive shaft and following this is a spinner knob which contains the mating half of the multi-jaw coupling, free to rotate on the shaft. On the rear side of the spinner knob is a driving pin which accurately engages at all times with a hole in the film sprocket proper and therefore serves to drive the latter. Between the spinner knob and the sprocket lies a compression spring which normally forces the spinner knob toward the fixed half of the multi-jaw coupling. By exerting an inward force on the spinner knob, the coupling becomes disengaged and the film sprocket is then "free-wheeled." Following the sprocket is a collar which is likewise driven by a pin engaging the film sprocket and rotates at all times with the sprocket. On the rear face of this collar is a ladder-chain sprocket which drives the footage counter in synchronism. Behind this is a smaller collar — fixed to the drive shaft

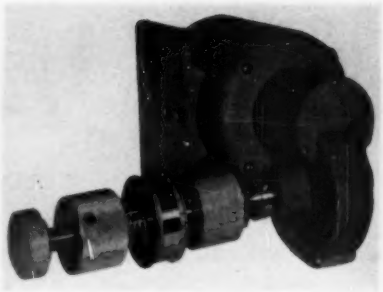

Fig. 9. Free-wheeling sprocket and drive-motor assembly.

— which forms an axial stop for the entire assembly when the foregoing items are assembled in their true position on the drive shaft. Since the film sprocket contains 32 teeth in the case of 35mm applications, a multi-jaw coupling also having 32 teeth was chosen. It follows therefore that synchronism is maintained within one sprocket pitch for 35mm film and to an even closer degree for 16mm film where the sprocket contains 20 teeth. This arrangement will advance or retract film through the driving mechanism at the rate of approximately 6 in. per revolution of the spinner knob.

D. Accessory Equipment. In the building-block plan, a number of accessories have been developed to provide additional conveniences in operation as well as a means of reducing production costs. These include: (a) magnetic erasing facilities while recording either single or triple tracks; (b) a predetermining rewind footage counter; and (c) photographic-type sound reproducers for both 16mm and 35mm films. The erasing unit employs two erase heads in cascade for each sound track, making a total of six heads in the unit. The geometry of the film path between feed reel and film-drive mechanism is slightly modified to bring the erase unit into use. This consists of threading the film about a series of

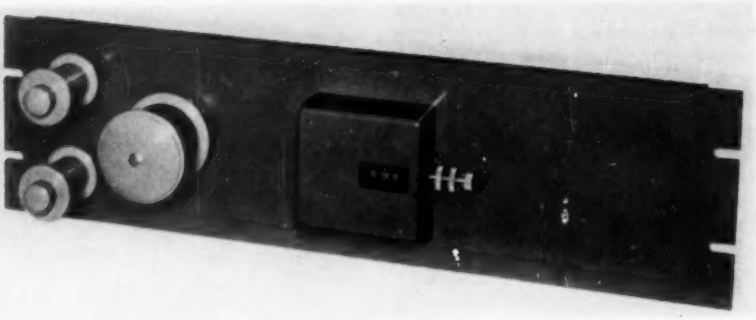

Fig. 10. Predetermining counter assembly.

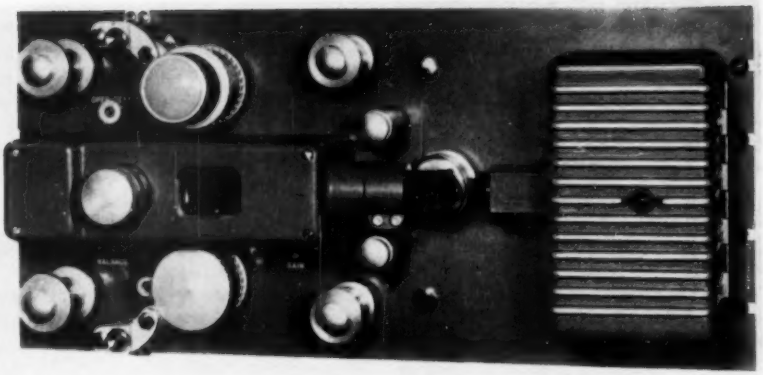

Fig. 11. 35mm photographic reproducer assembly.

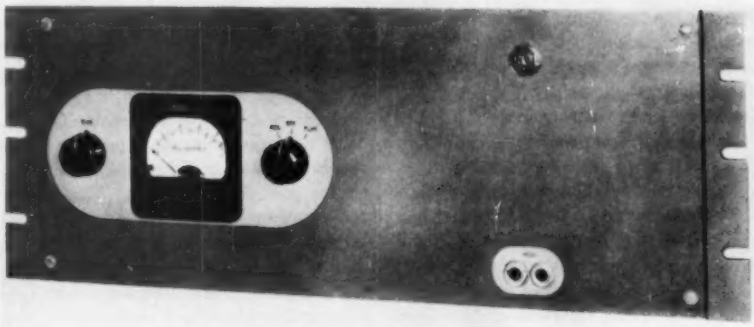

Fig. 12. Oscillator–preamplifier.

fixed rollers which allow the film to contact the erase heads. When erasing is not wanted, the film is threaded directly past the erasing unit. Thus, the difference in film threading, plus an enclosure around the erasing heads, reduces the accidental use of the erasing facilities to a minimum. Each erase head dissipates 1.6 w, making a total of 3.2 w per track of erase current power. The frequency is nominally 68 kc and derived from the recording bias oscillator. This amount of erase power provides a 70-db erasure below 100% modulation or results equivalent to that obtained by the conventional 60-cycle bulk eraser.

The predetermining footage counter accessory is shown in Fig. 10. It is used in rewinding to a given point without operator attention. A specific use for this convenience is, for example, in scoring music, where playbacks and transfers are involved. This assembly consists of a special counter which is film-driven and several additional relays in the electrical circuit for controlling the film feed and take-up torque motors. In operation, the counter is set to a given number of feet to be rewound and the rewind control switch positioned in the desired direction of rewinding. As the film travels from reel to reel, the counter subtracts toward zero. At 10 ft from zero the counter anticipates and trips an electrical control which applies a braking voltage to the respective torque motors. This braking action is maintained by a time-delay relay circuit during the deceleration period, and when the counter reaches zero both the braking action as well as the power are released. At this point, the torque motors are automatically restored to their normal functions of feed and take-up. The footage counter is driven by wrapping the film about a large rubber-tired roller, with the degree of wrap being maintained by two smaller rollers of the conventional type. When the predetermining counter operation is not wanted, the film path for rewinding is threaded to by-pass the counter drive. The electrical control elements have been designed to stop film travel within two to three feet of a given point, this point being in the direction of over-travel. The starting point is then brought into view during rethreading of the film-drive mechanism, since the operator's natural tendency is to pull this amount of slack film from the feed reel for the threading operation. Exact synchronism is then obtained by turning the free-wheeling sprocket.

The third accessory item is a photographic sound reproducer unit for both 16mm and 35mm applications. The latter, shown in Fig. 11, is suitable for 100-mil standard, 100-mil push-pull and 200-mil push-pull sound tracks. It is believed that most sound-recording plants find it necessary to handle photographic records at different times regardless of the extent of their magnetic plant facilities. Since many of the components of a magnetic reproducing channel might well be common to a photographic reproducing channel, it is logical that a dual-purpose reproducer will reduce the overall plant investment. Again the building-block plan permits the use of another unit in conjunction with those items considered common to either type of reproducer. The photographic sound reproducer need have only the necessary optical-scanning facilities and a means of directing the film for scanning. This has been accomplished by mounting the necessary optical elements on a panel $8\frac{3}{4}$ in. high and assembling in the standard relay rack directly below the magnetic film-drive mechanism. The photographic reproducer contains its own mechanical filter system but its driving power is derived from a synchronous rubber-belt drive from the magnetic film-drive unit. In operation, the film is threaded to by-pass the magnetic unit. Likewise, the photographic unit is by-passed when using the magnetic unit. Preamplifiers for both the 16mm and 35mm reproducers are mounted directly behind the respective mechanisms and

Fig. 13. Erase amplifier (front view).

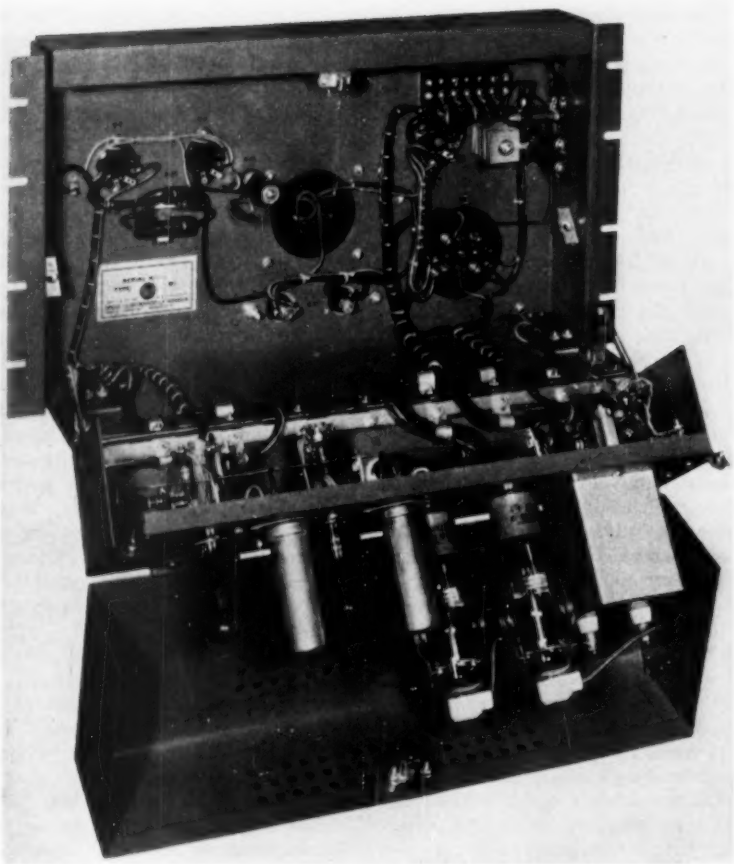

Fig. 14. Erase amplifier (service position).

provide an output level of approximately −2 dbm and −12 dbm, respectively.

A variety of amplifiers and bias oscillators are available to complement the above-mentioned alternative equipment arrangements. For single-track recording and reproducing, the amplifier-oscillator known as MI-10248 or MI-10248-A, shown in Fig. 12, is provided. This unit contains a combining network, bias oscillator and bias meter. In addition, it also provides for a separate self-contained playback amplifier capable of amplifying the signal from the monitor head to a level of +4 dbm. Output impedances of 10, 250 and 600 ohms are available so as to provide for headset monitor or for transmission to the re-recording channel. Suitable switching facilities deactivate the oscillator during playback or in the OFF position. The oscillator also contains a high-frequency boost equalizer which is used to shape the recording characteristic to obtain flat output to 8000 cycles. A separate winding on the oscillator coil permits connection to an MI-10263 Erase Amplifier as shown in Figs. 13 and 14. By means of this amplifier, it is possible to raise the output voltage from the oscillator to a level sufficient for erasing. This erase amplifier contains its own a-c power supply and is capable of delivering 50 w at 68 kc at a distortion of less than 0.5%. At normal erase power requirements, the wave-form distortion from this amplifier is on the order of 0.1% or less.

For triple-track recording or reproducing, a three-channel bias oscillator is provided. This oscillator, known as the MI-10228-A, is usually mounted together with the MI-10262-A Switching Panel on a common frame and is shown in Figs. 15 and 16. A master oscillator operating at a nominal frequency of 68 kc supplies three independent push-pull amplifiers which in turn furnish bias current to the three recording heads. The switching panel permits the combining of the bias currents with the signal before it reaches the heads and also provides switching means for turning the MI-10228-A oscillator on and off. Three separate bias meters are contained on the switching panel to permit independent metering of the three recording heads. For playback, there are available plug-in amplifiers (Fig. 17) which may be connected singly or in cascade so as to obtain almost any desired output level from the reproducing heads with frequency characteristics flat up to 8000 cycles. Six such playback amplifiers are housed on a common shelf. These six amplifiers furnish the playback amplification for a triple-track reproducing setup. For recording amplifiers, plug-in amplifiers, in external appearance very similar to the playback amplifiers, are available. However, any power amplifier capable of providing a level of +22 dbm at an output impedance of 600 ohms, may be used. In order to obtain the optimum signal-to-noise ratio, we have standardized on the use of a low-frequency pre-equalizer during recording. This unit, shown in Fig. 18, raises the 60-cycle region of the recording characteristic by 6 db and consequently permits the use of 6 db less post-equalization during reproducing. This expedient reflects in a gain in signal-to-noise ratio, since hum frequencies, such as 60 cycles, now require 6 db less playback amplification. The insertion loss of this constant resistance equalizer is 10 db. It may be connected before or after the power amplifier dependent on the power-handling capacity of this amplifier. The performance of these magnetic channels is best expressed by stating that the overall frequency response is flat within 1 db from 40 to 8000 cycles at film speeds of 90 or 45 fpm, and flat within 1 db from 50 to 7000 cycles at film speed of 36 fpm. The signal-to-noise ratio is consistently 60 db or better, referred to 100% modulated track. In order to obtain this performance, all heaters are operated from d-c supplies which have a ripple content of 6 mv or less. The ripple content of the B supplies is 1 mv or less. The flutter

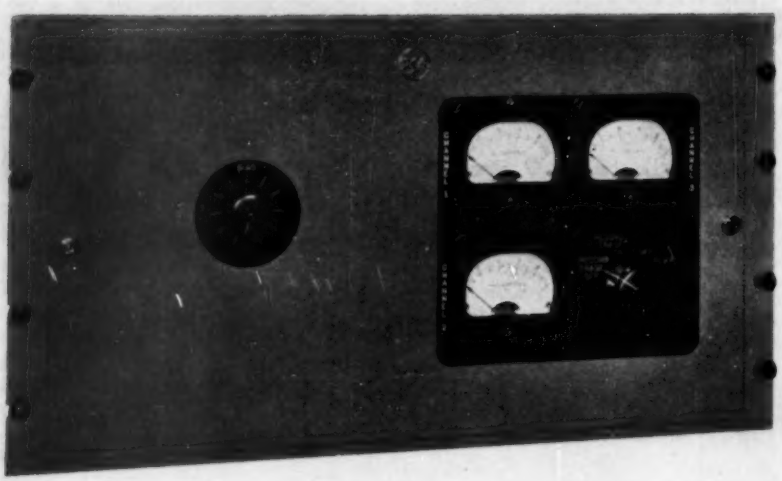

Fig. 15. Triple-track oscillator and switching panel.

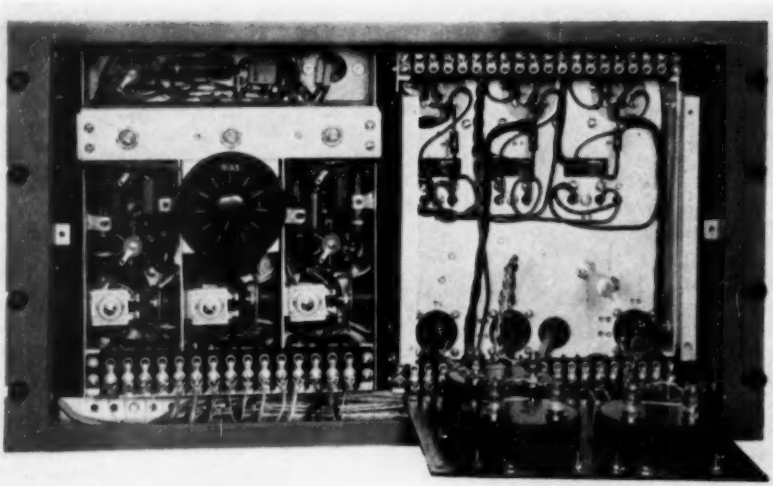

Fig. 16. Triple-track oscillator and switching panel (cover removed).

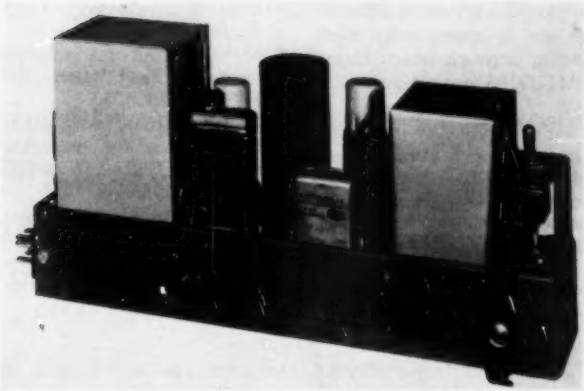

Fig. 17. Magnetic playback amplifier.

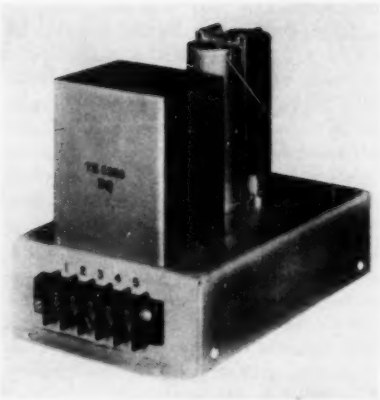

Fig. 18. Recording equalizer.

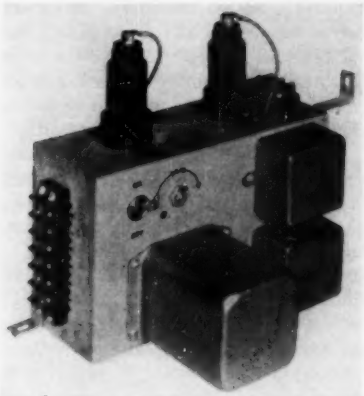

Fig. 19. 16mm photocell amplifier.

content of a recording reproduced on either single- or triple-track equipments is less than 0.1% rms total with less than 0.05% rms being 96 cycles flutter.[5] Rewinding speed is approximately 900 fpm. Starting time is in the order of 4 sec for 35mm or 17½mm equipment at 90 fpm, and approximately 5 sec for 16mm equipment at 36 fpm.

In order to complement the photographic-film reproducing facilities the following amplifiers are available:

1. For 16mm reproducing, the MI-10239-A, shown in Fig. 19, can be supplied. This is a two-stage negative feedback amplifier capable of furnishing photocell polarizing potential and of amplifying the output from a photocell to a level of −10 dbm.

2. For the reproducing of 35mm optical track there is available an amplifier of the plug-in broadcast type known as MI-10271 which in appearance is similar to magnetic playback amplifiers. This

amplifier also furnishes photocell polarizing potential and is customarily used with a balancing network which forms part of the MI-29135 optical system.

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A-C High-Intensity Arc Slide Projector

By ARTHUR J. HATCH

This paper describes a high-intensity arc slide projector which is powered from a 110-v, 60-cycle convenience outlet and requires only 10-amp supply. The resulting intensity of illumination is sufficient for screens of 35 ft in width.

A modern slide projector, shown in Fig. 1, using a high-intensity a-c carbon arc as a light source, has been developed to cover both the large-screen areas of drive-in theaters and smaller screens where an exceptionally high level of illumination is desired.

With this high-intensity a-c arc adapted for $3\frac{1}{4}$ in. by 4 in. slides, 7500 lm are projected, with no slide in the carrier. Expressed a different way, this 7500 lm projected to a 35-ft wide screen will produce a screen brightness of approximately 9 ft-L, which incidentally is the lower limit of the SMPTE screen brightness range for 35mm projection. For a 50-ft wide picture the screen brightness will be nearly equal to that usually obtained on the average 50-ft drive-in screen with 35mm projection.

With small-size screens of 10 to 12 ft in width, the brightness may approximate 70 ft-L, which is sufficient to obtain a reasonably good contrast even with the normal room lighting remaining on.

The complete projector comprises the arc lamphouse, optical system, slide carriers, and fan and transformer, all assembled as a table unit 78 in. long and weighing 175 lb. The table is adjustable in height by means of its four legs, from 36 in. to 56 in., and tiltable from 10° upward to 30° downward.

The reflector-type arc lamphouse and power supply elements are essentially the same units used in the "Trouper" arc spotlight.* The lamphouse is complete with carbon holders, motor-driven carbon feed, reflector tilt adjustments, arc focus knob and arc imager screen.

The trim of 6 mm by 7 in. copper-coated high-intensity a-c carbons is burned in coaxial alignment at 45 amp and 21 v a-c. The burning time for a single trim of carbons is 1 hr 20 min.

Although the first development with this new a-c projector has been for $3\frac{1}{4}$ by 4 in. slides, simple adaptations can be used to project both larger and smaller material. However, in the case of 2 in. by 2 in. material or smaller, heat-removing means in the form of heat filters or heat deflectors will have to be used in the light beam to prevent damage to the slide.

The optical system is arranged so that the light from the arc is gathered by a $10\frac{1}{4}$-in. diameter elliptical reflector which has a focus of $3\frac{1}{4}$ in. and a working distance of 24 in. This reflector converges the beam of light through a plano-convex lens and thence through the slide aperture to the objective lens.

Presented on April 22, 1952, at the Society's Convention at Chicago, Ill., by Arthur J. Hatch, The Strong Electric Corp., 87 City Park Ave., Toledo 2, Ohio.

* R. Ayling "New portable high-intensity arc spotlight," *Jour. SMPE, 53:* 408–416, Oct. 1949.

Fig. 1. A-C Arc Slide Projector.

The magnification of the carbon crater on the slide aperture is sufficient to cover a 2 in. by 2 in. slide. When $3\frac{1}{4}$ in. by 4 in. slides are projected, a negative lens is placed in the beam of light between the lamp and plano-convex lens to increase the magnification sufficiently to cover the larger aperture.

The power transformer which isolates the a-c line potential from the lamp-house draws 10 amp from any 115-v convenience outlet and delivers 45 amp at 21 v to the arc. The eight-point rotary tap switch and indicating meter provide a convenient means of compensating for commercial variations in the a-c line voltage.

The indicating meter, in reality a voltmeter with a suppressed zero, is connected across a portion of the transformer primary winding. When the hand of the indicating meter scales in the green zone, the volts per turn of the transformer primary are at the right value to deliver the correct amount of power to the arc. The tap switch is simply turned until the primary volts

per turn are correct as indicated by the meter.

A fan of 50 cu ft/min capacity directs a moving air stream across the slide to prevent damage to the slide. This fan is started when the arc power supply is turned on. With the cooling from this blower, it is possible to project dense $3\frac{1}{4}$ in. by 4 in. slides for periods of an hour or more continuously without visible deterioration to the slide.

The arc "on-off" switch is located at the top rear of the lamphouse. A manually operated dowser interposed just before the slide carrier and lens assembly enables the arc to be burned in a stand-by condition.

Single-element objective lenses have been found suitable for use with $3\frac{1}{4}$ in. by 4 in. slides in the focal length range of 17 in. to 30 in. Corrected objective systems are generally necessary for focal lengths shorter than 17 in.

Discussion

J. A. Tanney (*S.O.S. Cinema Supply Corp.*): Have you had any experience with wide-angle lenses of comparatively short throw?

Mr. Hatch: I understand that there is a type of lens which has recently appeared which will give a wide-angle picture with a very short throw. It is possible that such an objective system could be coupled with this projector.

Mr. Tanney: What I had in mind was its possible ues in TV studios for backgrounds or in motion picture work for still backgrounds.

Mr. Hatch: We are going to investigate those possibilities in connection with this projector.

Proposed American Standard

PH22.90 Aperture Calibration of Motion Picture Lenses

STARTING ABOUT 1940, there has been a rapidly growing need in the motion picture industry for a more accurate expression of the photographic speed of a lens than is afforded by the simple *f*-number ratio. The Proposed American Standard appearing on the following pages is the product of many years' industrious and patient effort to achieve agreement on a standard photometric method of aperture calibration. It is published here for 6-month trial and criticism. All comments should be sent to Henry Kogel, SMPTE Staff Engineer, prior to April 15, 1953, along with a carbon for R. Kingslake, Chairman of the Optics Committee.

The problem is essentially this: the density of a photographic image depends on (a) the brightness of the subject, (b) the effective speed of the lens, (c) the speed of the film, (d) the exposure time, and (e) processing of the film. In modern motion picture production all these factors except (b) are controlled or known to within a few per cent, but the supposed speed of the lens may be in error by as much as 60 or 70%. This is caused by loss of light through surface reflections or direct absorption in the lens, and occasionally to incorrect marking of the *f*-number scale.

By August 1947, no less than eight papers on lens calibration had appeared in this JOURNAL.

The Standards Committee, therefore, formed a Subcommittee on Lens Calibration to study the whole subject and to recommend a standard procedure for measuring the effective photographic speed of a lens. In October 1949 the Subcommittee published a report of their investigations and recommendations, which became the basis of the present proposal. The introduction to the report stated in part: "The demand for a photometric type of aperture calibration ("T-stop") is becoming increasingly felt, and it has the advantage that diaphragms of any shape, pentagonal, scalloped or irregular, can be correctly labeled with as much ease as a circular one. The presence or absence of antireflection coatings is automatically accounted for in the calibration, and so also are factory variations in the focal length and in the iris mechanism. Illumination on the film in the center of the field will therefore be the same for all lenses at the same T-stop, assuming that the object is a uniform plane surface perpendicular to the lens axis. It is implicit, also, that each lens shall be individually calibrated if the photometric method is used."

In November 1949 the Subcommittee was given formal status of its own in the creation of the Optics Committee under the chairmanship of Mr. Kingslake. This Committee achieved agreement on the final version of the proposal at its May 3, 1951, meeting and forwarded it to the Standards Committee for processing as an American Standard. The ballot of the Standards Committee on the question of preliminary publication brought forth several negative votes, all of which were based on objections to paragraphs dealing with some of the practical applications of T-stops. These were not fundamental aspects of the proposal and have therefore been eliminated, paving the way for its present publication.

Proposed American Standard

Aperture Calibration of Motion Picture Lenses

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1. Scope

1.1 The purpose of this standard is to define the *f* and T numbers used to express the relative aperture of a photographic objective. A second purpose is to establish means for calibrating the diaphragms of objectives in both the *f* and T systems, with suitable tolerance specifications.

1.2 The *f* number of a lens represents a true geometrical measure of the relative aperture.

1.3 The T number is a photometrically determined measure of the relative aperture of a lens adjusted to take proper account of the lens transmittance, so that the illuminance in the center of the lens field will be the same for all lenses at the same T-stop setting. This assumes that the object is a uniform plane diffusing surface perpendicular to the lens axis.

1.4 It should perhaps be mentioned that the photometric calibration of a lens diaphragm as contemplated by the T system of diaphragm marking established by this specification is only one step in extending the control for the purpose of producing negatives of a desired uniform density. The density of a negative is dependent upon the illumination and reflectance of the object photographed, the correctness of the diaphragm marking, the absorption of the lens, the accuracy of timing of the exposure, the uniformity of the emulsion employed, and complete control of the processing. The application of the T-stop system is designed to improve the control as regards correctness of diaphragm marking and absorption of the lens. The importance and need for this particular control increases as the control of the other factors enumerated is improved.

2. Theory

2.1 The illuminance at the center of the image of a uniform plane extended object perpendicular to and centered on the lens axis, when the lens has a circular aperture, is given by

$$E = \pi t B \sin^2\theta \qquad (1)$$

2.2 In this formula: E is the illuminance in lumens per unit of area; t is the lens transmittance, expressed as the ratio of emerging flux to entering flux for a beam sufficiently narrow to pass through the lens without obstruction by the lens mount; B is the object luminance in candles per square unit; and θ is the semi-angle of the cone subtended by the circular exit pupil of the lens at the point where the lens axis intersects the image plane.

2.3 If the lens can be assumed to be aplanatic, that is, to be free from spherical aberration and to satisfy the sine condition, and if the object is very distant, then the value of sin θ will be given by

$$\sin\theta = \frac{Y}{f} \qquad (2)$$

where Y is the semidiameter of the circular entrance pupil of the lens and *f* is the focal length. The validity of this equation may be seen by reference to Fig. 1, remembering that in a lens having the type of correction assumed in this paragraph, the principal planes of Gauss are in reality portions of spheres centered about the axial object and image points, respectively.

2.4 If the lens aperture is not circular, which will often occur when the iris is partly closed, the angle θ has no meaning. In such a case, we may define the effective diameter, D′, of the entrance pupil in terms of its area, A, by

$$A = \frac{\pi D'^2}{4} \qquad (3)$$

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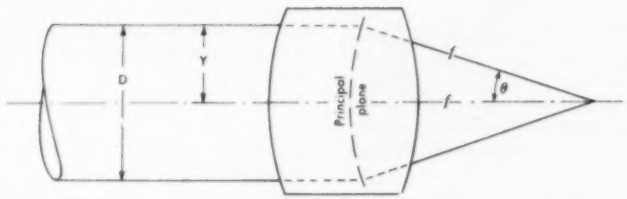

Figure 1

whence $$D' = 2\sqrt{\frac{A}{\pi}} \qquad (4)$$

2.5 For an aplanatic lens, we may now replace sin θ by $D'/2f$, and the image illuminance equation (1) becomes

$$E = \pi \tau B (D'/2f)^2$$

whence by equation (4), we find

$$E = \tau BA/f^2 \qquad (5)$$

3. Definition of *f* Number

3.1 For a lens of the type assumed, having a circular aperture, which is perfectly corrected for spherical aberration and satisfies the sine condition, and which is also assumed to form an image in air of a very distant object, the *f* number of the lens is defined by the equation

$$f \text{ number} = \frac{f}{D} = \frac{1}{2 \sin \theta_0} \qquad (6)$$

where θ_0 is the semiangle of the cone subtended by the circular exit pupil of the lens at the point where the lens axis intersects the plane of the image of the assumed distant object, and the entrance pupil has a diameter D.

3.2 If the entrance pupil is not circular, this relation becomes

$$f \text{ number} = \frac{f}{D'} = \frac{f}{2\sqrt{\frac{A}{\pi}}} \qquad (7)$$

following the reasoning of Section 2.4.

3.3 If the aperture is circular, but the lens does not satisfy the sine condition, then f/D will not be equal to $1/(2 \sin \theta)$. In such a case, the *f* number of the lens is to be defined by $1/(2 \sin \theta)$ rather than by the ratio f/D. This value is chosen because both the image illuminance and the depth of field of the lens depend directly on sin θ. In such a lens, then, the marked *f* number will not be equal to the simple ratio of the focal length to the diameter of the entrance pupil.

3.4 The procedure for measuring the *f* number of a lens with a distant object is given in Section 11.

3.5 In terms of *f* number, equation (1) giving the image illuminance becomes

$$E = \pi \tau B/4(f \text{ number})^2 \qquad (8)$$

4. Effective and Equivalent *f* Number of a Lens Used at Finite Magnification

4.1 If a lens with a circular aperture is used to form an image at a finite magnification m, the image illuminance will, as always, be given by equation (1).

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4.2 The Effective *f* number of the lens, which is to be used to determine the image illuminance by equation (8), is then defined by

$$\text{Effective } f \text{ number} = \frac{1}{2 \sin \theta_m} \quad (9)$$

where θ_m changes as the magnification m increases.

4.3 For an infinitely thin lens, or for a thick lens in which the entrance and exit pupils coincide with the first and second principal planes, respectively, and in which the light beam is limited only by the iris diaphragm, the Effective *f* number will be related to the *f* number by

$$(\text{Effective } f \text{ number for magnification m}) = (f \text{ number})(1 + m) \quad (10)$$

4.4 However, many lenses cannot be regarded as being "thin," and in such cases the Effective *f* number at a finite magnification will not * be equal to the infinity *f* number multiplied by (1 + m). However, the photographer knows from long experience that he should always multiply the marked *f* number of a lens by (1 + m) in order to determine the Effective *f* number at a finite magnification m. Therefore, in order that this procedure can continue to be used, it is suggested that if a lens is designed to work at or near some particular finite magnification m, the aperture markings should be engraved with the "Equivalent *f* number" defined by

$$\text{Equivalent } f \text{ number} = \left[\frac{\text{Effective } f \text{ number at magnification m}}{1 + m}\right] \quad (11)$$

5. Definition of T Number

5.1 When lenses are marked in accordance with the *f* system, differences of value in the factor t of equation (1) are completely ignored, with the consequence that for a given *f*-setting of the diaphragms, even though correctly marked, the exposures made with different lenses may vary greatly, this variation arising from a variation in the number of component elements of the different lenses and from the large differences in the values of transmittance that exist between coated and uncoated lenses. The T system defined in this section is a new system of diaphragm graduation designed to compensate for this variation. With the T system of graduation the image illuminance in the center of the field is independent of the variations in lens structure enumerated above.

5.2 For a lens used with a distant object, the T number is defined as the *f* number of an ideal lens having 100 per cent transmittance and a circular aperture, which would give the same central-image illuminance as the actual lens at the specified stop opening.

5.3 Hence, for a lens with a circular aperture, following the argument of equation (8),

$$\text{T number} = \frac{f \text{ number}}{\sqrt{t}} \quad (12)$$

and for a lens with an entrance pupil of any shape and area A, the corresponding formula is

$$\text{T number} = \frac{f}{2\sqrt{\frac{\pi}{t A}}} \quad (13)$$

5.4 In practice, however, it is expected that the normal procedure will be to re-engrave the diaphragm ring on the lens at a series of

* For example, an afocal lens of symmetrical construction can be used as a printer or copying lens at unit magnification. The Effective *f* number is then equal to the *f* number of the half system, but since the focal length of the whole lens is infinite, no meaning can be given to the *f* number of the whole system. For other examples see: R. Kingslake, "The effective aperture of a photographic objective," J. Optical Soc. Am., vol. 35, pp. 518–520 (1945).

definite T numbers, rather than to measure the T number corresponding to each of the existing marked *f* numbers.

5.5 It may be remarked again that the T number is a photometrically determined quantity, whereas the *f* number is a geometrical quantity. Since the T numbers are determined photometrically, they automatically take account of the size and shape of the aperture, the actual focal length of the lens, the lens transmittance, and any internally reflected stray light which may happen to strike the film at the center of the field (such as in a flare spot). It is implicit in the T number system of aperture markings that every lens should be individually calibrated.

5.6 For a lens designed to be used at finite magnification, the engraved T number will correspond to the Equivalent *f* number defined by equation (11).

5.7 The procedure for measuring the T number of a lens is given in Section 13.

6. Standard Series of Aperture Markings

6.1 The diaphragm ring of a lens shall be marked at every whole stop on either system. A "whole stop" is taken to represent an interval of double or half the image illuminance, corresponding to a ratio of $\sqrt{2}$ or $\sqrt{0.5}$ in the diameter of a circular lens aperture. By convention, the series of whole stop numbers to be used are accurately:

0.71, 1.00, 1.41, 2.00, 2.83, 4.00, 5.66, 8.00, 11.3, 16.0, 22.6, 32.0, ...

6.2 These marks shall be engraved on the lens as follows: 0.7, 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32. The maximum aperture of the lens shall be marked with its measured *f* number or T number, stated to one decimal place. These recommendations follow American Standard Z38.4.7–1943.

6.3 In setting the lens aperture, it is assumed that the diaphragm ring will always be turned in the closing direction, and not in the opening direction; this is to eliminate backlash effects.

7. Subdivision of a Whole Stop

7.1 If it is desired to subdivide a "whole stop" interval, we may refer to a fraction S of a stop, defined so as to yield a ratio of image illuminance R equal to 2^S or $(0.5)^S$. Then, for any given illuminance-ratio R, the corresponding fraction of a stop will be given by $S = (\log R)/(\log 2) = 3.32 \log R$. A few typical examples are given in the following table:

Fraction of a Stop (S)	Illuminance Ratio (R)
one-tenth	1.072 or 0.932
one-sixth	1.122 or 0.891
one-quarter	1.189 or 0.841
one-third	1.260 or 0.793
one-half	1.414 or 0.707
two-thirds	1.587 or 0.630
three-quarters	1.682 or 0.594
a whole stop	2.0 or 0.5

7.2 When engraving a lens, each whole stop interval may be divided into three subdivisions by dots or marks (not numbered), the dots being at "thirds of a stop," namely, 0.7, 0.8, 0.9, 1.0, 1.13, 1.27, 1.4, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.2, 3.6, 4.0, 4.5, 5.0, 5.6, 6.3, 7.1, 8.0, 9.0, 10.0, 11.3, 12.7, 14.2, 16, 18, 20, 23, 25, 28, 32, ...

7.3 The reason for dividing each stop interval into three parts is so that the lens apertures will agree with the exposure-meter markings stated in American Standard Z52.12–1944, page 5. The same cube-root-of-two series is used for the Exposure Index of a film,

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see American Standard Z38.2.1–1947, page 11. One-third of a stop represents a logarithmic illumination ratio equal to 0.1, which is the transmittance of a neutral density of 0.1. The ratio of successive circular stop diameters is equal to $\sqrt[6]{2} = 1.123$.

8. Symbols

8.1 Lenses calibrated on the *f* system should bear the designation *f*/ or *f*: followed by the numerals (see American Standard Z38.4.7–1943).

8.2 Lenses calibrated on the T-stop system should bear the designation T or T— followed by the numerals.

9. Accuracy of Marking (*f* System)

9.1 The maximum opening of a lens on the *f* system shall be marked with an accuracy of ± 12 per cent of area, or ± 6 per cent of diameter.*

9.2 NOTE: Since in most factories a blanket calibration is generally used for the *f* apertures of a complete run of lenses of the same type, the smaller openings may be in error by ± 25 per cent of area, or ± 12 per cent of diameter (one-third of a stop), particularly in short-focus lenses. These figures are based on the assumption that the iris will always be closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects.

* Z38.4.4–1942 the engraved focal length of lenses for still picture photography must be within ± 4 per cent of its true value, and in Z38.4.7–1943 the measured diameter of the maximum entering beam shall be at least 95 per cent of the quotient obtained by dividing the engraved focal length by the engraved *f* number. Thus by combining these tolerances we find that the diameter of the maximum lens aperture may be in error by as much as 9 per cent. This represents an error in area of 18 per cent, or one-quarter of a stop, which is felt to be unnecessarily large for the maximum aperture. The proposed tolerance on aperture marking for motion picture objective lenses allows less latitude than that provided for still picture camera lenses by Sectional Committee Z38 (Photography), because of the stricter requirements in cinematography on the same continuous length of film using different lenses.

10. Accuracy of Marking (T System)

10.1 Since each lens is individually calibrated, an accuracy of one-sixth of a stop (10 per cent in illumination or 5 per cent in diameter) becomes entirely possible throughout the whole range of the diaphragm scale. This is assuming that the diaphragm is always closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects.

10.2 Alternatively, the manufacturer should be prepared to guarantee this accuracy even though each stop marking may not be individually determined.

10.3 It may be of interest to indicate the approximate magnitude of this tolerance. Since 5 per cent in diameter corresponds to 5 per cent in *f* number, a lens of aperture nominally *f*/2 may be anywhere between *f*/1.90 and *f*/2.10. A lens nominally *f*/4.5 may lie between *f*/4.28 and *f*/4.72; and a nominal *f*/8 may lie anywhere between *f*/7.6 and *f*/8.4.

11. Measurement of *f* Apertures (Distant Object)

11.1 The procedure for measuring the *f* number of any lens having a circular diaphragm aperture is described in American Standard Z38.4.20–1948, paragraph 3.

11.2 If the entrance pupil is noncircular, it is necessary to measure its area. This may be done conveniently by mounting a point source

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of light such as a small hole in front of a lamp bulb, or a 2-watt zirconium lamp, at the rear focal point of the lens, and allowing the light beam which emerges from the front of the lens to fall upon a piece of photographic material. After processing, the recorded area is measured with a planimeter and applied in equation (7). If the lens is too small for this procedure to be employed, it may be placed in a suitable telecentric projector working at a known magnification (a workshop profile projector is suitable), the back of the test lens being towards the source of light. The entrance pupil then will be projected onto the screen of the projector at a known magnification, whence its area can be determined with a planimeter.

12. Measurement of *f* Apertures (Near Object)

12.1 To measure the Effective *f* number of a lens when used with a near object, it is necessary to determine the angle θ in equation (9). This may be done by using a point source of light at the correct axial object position, and measuring the diameter of the emerging beam at two widely separated planes a known distance apart. A simple computation will enable the semicone-angle θ to be determined.

12.2 The Effective *f* number is defined by $1/(2 \sin \theta)$; and the Equivalent *f* number for engraving on the lens barrel will then be equal to the Effective *f* number divided by $(1 + m)$, where m is the image magnification. (See Section 4.4 above.)

13. Photometric Calibration of a Lens

13.1.1 Since T-stops are based on a measurement of the illumination produced by the lens at the center of the field, it is first necessary to define the latter term. For the purpose of illumination or flux measurements, the term "center of the field" shall be taken to mean any area within a central circle approximately 3 mm in diameter for 35mm or 16mm frames, or 1.5 mm in diameter for 8mm frames.

13.1.2 The light used in making the determination shall be white,* and the sensitivity characteristic of the photoelectric receiver shall approximate that of ordinary panchromatic emulsion.† It is considered that these factors are not at all critical and no closer specification than this is necessary. Obviously errors will arise if the lens has a strongly selective transmission, but such lenses would be undesirable for other reasons.

13.1.3 The incident light shall fill a circular field whose angular diameter is no more than 10 degrees in excess of the diagonal of the intended angular field of the lens itself. During measurement, the light shall traverse the lens in the direction ordinarily employed in photography.

13.1.4 The lens should be carefully examined before calibration to ensure that there are no shiny regions in the barrel which would lead to flare or unwanted stray light, since this would vitiate the measurements badly. The lens surfaces should be clean.

13.2 Corner-to-Center Ratio. Having calibrated the stop markings of the lens on the T system by one of the methods to be described, the observer may, if desired, determine in addition the ratio of corner illumination to center illumination, at full aperture and

* Specifically a tungsten filament lamp operating between 2900 and 3200 degrees Kelvin.

† A suitable cell is one having an S-3 surface, combined with a Corning 9780 glass filter about 2.5 mm thick.

preferably at other apertures also. For this purpose the 3-mm (or 1½-mm) hole shall be used first at the center of the field, and then moved outwards until its rim is touching the top and side limits of the camera gate. This distance is shown in Table I.

Table I

Gate, Mm	Radial Shift of Hole, Mm
35 (16.03 × 22.05)	11.5
16 (7.47 × 10.41)	4.5
8 (3.51 × 4.80)	2.0

13.3 Extended-Source Method of T-Stop Calibration (distant object).

13.3.1 This method of lens calibration has been described by Gardner[13] and Sachtleben,[9] the underlying theory being given by McRae.[4] It is based on filling the lens with light from an extended uniform source, and placing a metal plate in the focal plane of the lens with a 3-mm hole (or 1.5-mm for 8-mm film) at its center. The light flux passing through the hole is measured by a photocell arrangement. This flux is then compared with the flux from the same source passing through the same hole from an open circular aperture of such a size and at such a distance from the plate that it subtends the desired angle θ referred to in equation (2) above. The greatest care is necessary to ensure that the extended source is really uniform, and also constant throughout the measurements. The open circular aperture is used as the "ideal lens with 100 per cent transmittance" referred to in Section 5.2.

13.3.2 It should be noted that this procedure measures the T-stop Aperture Ratio of the lens directly, regardless of whether or not the lens is aplanatic.

13.3.3 In practice, the photocell reading for each whole T-stop number is first determined for a series of open apertures, at a fixed distance from the plate. The lens is then substituted for the open aperture with the 3-mm hole accurately in its focal plane, and the iris of the lens is closed down until the photocell meter reading produced by the lens is equal to each of the successive open-hole readings. The full T-stop positions are then marked on the diaphragm ring of the lens. The intermediate third-of-a-stop positions may be found with sufficient accuracy by inserting a neutral density of 0.1 or 0.2 behind each open aperture in turn and noting the corresponding photocell readings.

13.3.4 The following table of aperture diameters may be useful. They are based on a distance of 50 mm from aperture to plate. (It is important to remember the difference between sine and tangent, and that the aperture diameter is not found merely by dividing 50 mm by the T number.)

Table II

Desired T Number	Value of θ = Cosec^{-1} (2 × T number), Degrees	Diameter of Aperture = 100 tan θ, mm
0.5	90	∞
0.71	45	100
1.00	30	57.74
1.41	20.708	37.80
2.00	14.478	25.82
2.83	10.183	17.96
4.00	7.181	12.60
5.66	5.072	8.88
8.00	3.583	6.26
11.31	2.533	4.42
16.00	1.791	3.12
22.63	1.266	2.21
32.00	0.895	1.56

13.3.5 A single set of apertures is sufficient to calibrate lenses of all focal lengths, since the only factor involved is sin θ, and that is

fixed by the aperture used. The apertures should be bevelled to a sharp edge, and well blackened on both sides.

13.3.6 The extended source should be uniformly bright over its useful area to within ± 3 per cent. (This can be tested with a suitable telephotometer, or a small hole in an opaque screen can be moved around in front of the source, and any consequent variations in photocell reading noted.) The source conveniently may be a sheet of ground glass covering a hole in a white-lined box containing several lamps mounted around the hole and shielded so that no direct light from the lamps falls on the ground glass itself.

13.3.7 The photocell receiver conveniently may be of the phototube type with a simple direct-current amplifier.* Care must be taken to ensure that the phototube sensitivity and the line voltage do not change between making readings on the open aperture and on the lens itself; to guard against this, some convenient turret arrangement is desirable with the lens on one side and the open aperture on the other so that the two may be interchanged and compared immediately with each other by merely turning the turret.

13.3.8 To measure the corner-to-center illumination ratio, then lens is set in position and the 3-mm hole and the photocell are displaced laterally by the desired amount. The photocell reading is noted at axial and corner positions, and the corresponding light ratio found from a calibration curve of the photocell meter.

* Suitable systems are the "Electronic Photometer" model 500 (Photovolt Corporation, 95 Madison Ave., New York, N. Y.), and the "Magnephot" (W. M. Welch Scientific Co., 1515 Sedgwick St., Chicago, Ill.). It is felt that a barrier-layer cell, although desirable for reasons of simplicity, has insufficient sensitivity for accurate determinations of the smaller apertures unless a galvanometer of exceptionally high sensitivity is employed.

13.4 Collimated Source Method of Lens Calibration.[13]

13.4.1 This method has been described by Daily [11] and Townsley,[14] the underlying theory being embodied in Section 5 above. Light from a small source (a 5-mm hole covered with opal glass and strongly illuminated from behind) is collimated by a simple lens, or an achromat if preferred, of about 15 inches focal length and 2 inches aperture. This gives a collimated beam which will be focused by the test lens to form a small disk of light in its focal plane. This circle of light will be less than the prescribed limit of 3-mm diameter for all lenses under 9 inches in focal length. Uniformity of the collimated beam can be checked by moving a small hole in an opaque screen across the beam, and any variations in the photocell reading noted.

13.4.2 For the comparison unit, an open aperture is used, of diameter equal to the focal length of the lens divided by the desired T number. This aperture is first mounted in front of an integrating sphere with the usual photocell detector, and the light from the collimator is allowed to enter the aperture. The aperture plate is now replaced by the lens, the iris diaphragm is closed down to give the same photocell reading, and the T-stop number is engraved on the iris ring. The intermediate thirds of stops can be added by using 0.1 or 0.2 density filters as in the method of Section 13.3.3.

13.4.3 To guard against drift and line-voltage variations which might occur between the readings on the comparison aperture and on the lens, it is convenient to leave the known standard aperture in place in front of the sphere, and to insert the lens into the beam in

such a position that the little image of the source falls wholly within the standard aperture. The meter reading should then remain the same no matter whether the lens is in or out of the beam. A second plate with a 3-mm aperture should be placed over the comparison aperture while the lens is in place to stop any stray light which may be reflected from the interior of the lens.

13.4.4 It should be noted particularly that if this method is used, the focal length of the lens must be measured separately, and a suitable set of open apertures constructed for use with it. However, by suitable devices, one single set of fixed apertures may be used for all lenses, as described by Townsley.[14]

13.4.5 It should also be noted that this procedure measures *f* number as the ratio of *f*/*D*, and the measurement is thus influenced by the state of correction of the lens in regard to spherical aberration and sine condition.

13.4.6 The corner-to-center ratio at any desired aperture can be conveniently determined by simply rotating the lens through the desired field angle ϕ and comparing the photocell reading with its value for the lens axis. The light-flux ratio can then be read off a calibration curve for the photocell system, and converted to the desired corner-to-center illumination ratio by multiplying it by $\cos^3\phi$. (Note that this procedure will be correct only in the absence of distortion, but no motion picture lens is likely to have enough distortion to cause any significant error.)

13.5 T-Stop Calibration at Finite Magnification.

13.5.1 To use the extended source method (see Section 13.3), it is only necessary to mount the metal plate at the desired image distance from the lens instead of placing it in the focal plane. The open apertures used for comparison must be calculated to have an opening corresponding to the desired Equivalent *f* number multiplied by (1 + m). This is because we are really comparing the illuminance given by the lens with the Effective *f* number of the open hole, but the engraving must be done at each standard step of the Equivalent *f* number (see Section 12.2.)

13.5.2 The collimated source method cannot be used to calibrate a lens at finite magnification.

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NOT APPROVED

International Standardization

By F. T. BOWDITCH, SMPTE Engineering Vice-President

On last June 9, 10 and 11 at Columbia University, the first meetings of Technical Committee 36 on Cinematography of the International Organization for Standardization were held. This is the standards group charged with the preparation of world standards in fields of cinematography, under the Secretariat of the American Standards Association. A following report by Henry Kogel will give details of the several subjects discussed. We will consider here our general impressions of this very interesting event.

Contrary to the final feeling of a worth-while job well done, those of us from the United States who took part in this affair did so largely from a sense of duty to the Secretariat responsibilities of the ASA. None of us had any previous experience in international deliberations of this sort, and we were uncertain as to how much could be accomplished. At the end of three days of close association with our foreign colleagues, however, the opinion was enthusiastically unanimous that the meetings had been very much worth while; the only complaint to come to my attention concerned the schedule, in which only two days had been allocated to TC36. Arrangements were made on the second day to continue for a third, and everyone felt that a full week could have been spent with profit; as a matter of fact, with a series of group meetings burning the midnight oil on both Monday and Tuesday evenings, a good week's work was actually crowded into those three days.

In addition to the U.S. delegation, the meetings were attended throughout by representatives of Canada, France, Germany and the United Kingdom. A Belgian representative joined us occasionally, and a space was continually reserved for the U.S.S.R., whose delegates were somewhere about, but scheduled uncertainly between cinematography and other concurrent meetings. The Russians never did visit us, which was a matter for some disappointment curiosity-wise, although the complication of a second translation of all remarks would undoubtedly have slowed our progress. As it was, the remarks of the delegate from France, M. Jean Vivié, were always made in his native tongue, with frequent pauses for translation into English; while the remarks of all other delegates in English were translated into French for M. Vivié. This would at first seem to delay things immeasurably, but we were fortunate in having a most capable interpreter, Mr. L. Foy, whose repertoire included perhaps ten languages any one of which he could translate extemporaneously and unhesitatingly into any other. He soon developed an amazing knowledge of motion picture technology and so operated with the highest efficiency.

The formal meetings were opened on Monday morning, June 9, by Vice-Admiral G. F. Hussey, Jr., Managing Director of the ASA. He introduced D. E. Hyndman, who delivered the welcoming address, calling attention not only to the great importance of international standards in facilitating world trade, but pointing out the forthcoming significance of television as an international force, and predicting a growing interest of TC36 in world

standards for this specialized form of motion pictures.

Dr. L. Knopp, delegate from the United Kingdom and President of the British Kinematograph Society, then proposed that the writer be elected as Chairman of the meeting, which was promptly done. This responsibility was approached with some uncertainty, but was soon exercised with greater confidence as the fine cooperative spirit of the delegates became apparent, and as the bilingual machinery operated with much greater smoothness than we had anticipated. Mr. W. Rambal of the central ISO office in Geneva sat at the Chairman's right in the first sessions, to offer helpful advice on parliamentary matters as needed.

As things developed, the formal meetings of the whole Committee were soon abandoned in favor of a series of six Working Group meetings on as many different subjects. These were attended by all the foreign delegates and by a limited number of U.S. delegates most interested in each particular subject. Chairmanships of these Working Groups were delegated to the French, German and United Kingdom representatives, as well as to the U.S., and all were conducted in a most efficient manner. Jean Vivié of France, Dr. Leo Busch and Wilhelm Waegelein of Germany, and Dr. L. Knopp and H. L. Griffiths of England worked tirelessly and conscientiously with all these groups, till late at night on Monday and Tuesday, and starting again early each morning. Gerald Graham of Canada was also present, but only as an observer since his country is not represented as a full working member of TC36; Mr. Foy, our indefatigable translator, was ever-present to bridge the language barrier. The U.S. delegation of 20 persons, ably headed by Dr. D. R. White, chairman of ASA Sectional Committee PH22 on Motion Pictures, had a somewhat easier time of it, with a different small number at each group meeting. The many months of preparation by PH22 and by the several Engineering Committees of SMPTE proved exceedingly helpful here, as did the active participation of The Motion Picture Research Council. W. F. Kelley of the Council cooperated in all the group meetings, giving much helpful advice where motion picture studio considerations were involved.

Minutes of each meeting and copies of all resolutions were prepared in time for distribution at the next session, mimeographed both in French and in English. This required that an English version be prepared at the earliest possible moment. Henry Kogel, Staff Engineer of SMPTE, was of much service here, cooperating with J. W. McNair, Miss Virginia Kelly and Miss Carolyn Locher of ASA to get all of our deliberations correctly recorded.

At the final formal meeting of TC36 on Wednesday afternoon, it was agreed that all the Working Groups should be continued on a more permanent basis, under the chairmanships first assigned. It seems certain that cooperation via correspondence will now be very much more effective than before these personal acquaintanceships were made. Certainly the foreign delegates gave every evidence of a high degree of competence and sincerity, and in all instances were very well prepared to discuss the various matters on the agenda.

The U.S. delegates had also come well prepared and with open minds, as witness the agreement to recommend as a World Standard a picture-to-sound separation of 21 frames for 35mm film. The present American Standard specifies this distance to be only 20 frames, and any change at first seemed to be an altogether futile attempt to change a well-established U.S. practice. It soon developed, however, that the U.S. practice is in fact to use the 21-frame separation: projectors are threaded at 20-frames, but the studios adjust the sound-to-picture separation on the film to give

synchronization to an observer seated 50 ft from the screen. Some years ago this 21-frame French proposal was received in the U.S. via correspondence, and circulated here for comment over a period of months, with unanimous agreement that it would be impractical for the U.S. to change. A half-hour's direct conversation with the French, English and German delegates brought out the fact noted above, that the U.S. has been using this proposal all along — only the standard itself needs to be changed to bring everything into agreement!

The opportunity of serving as the chairman of this first meeting of ISO/TC36, although approached with some uncertainty, is looked back on with deep appreciation. This was a most heartening experience, and all who contributed to these meetings have the right to feel that the work of TC36 has now been given a most effective start. When men of good purpose sit down together and talk things over, much can be accomplished, as witness the following report by Henry Kogel. We are proud and happy to have played a part.

Agenda and Accomplishments of ISO/TC 36 Meeting

By HENRY KOGEL, SMPTE Staff Engineer

THE PRECEDING REPORT on international standardization by F. T. Bowditch has clearly outlined the general aspects of the three-day meeting, June 9–11, of Technical Committee 36 on Cinematography of the International Organization for Standardization (ISO/TC 36). It is, therefore, the intent to present here only the specific details considered and the concrete results to date.

The draft agenda was considered first, then amended slightly. It is given below in its final form along with the Working Group associated with each item.

1. Welcoming Remarks, D. E. Hyndman
2. Introduction to Those Present, G. F. Hussey, Jr.
3. Opening Remarks by the Chairman, F. T. Bowditch
4. Approval of Agenda
5. Review of Scope
6. Dimensions of Raw Stock — Work Group 1, chaired by D. R. White, United States
7. Definition of Safety Film — Work Group 2, chaired by Leslie Knopp, United Kingdom
8. Emulsion and Sound Record Position in Cameras and Projectors — Work Group 3, chaired by Leo Busch, Germany
9. Dimensions and Location for Sound Records and Scanning Area — Work Group 4, chaired by Malcolm Townsley, United States
10. Location and Size of Picture Apertures in Cameras, Projectors and Printers — Work Group 5, chaired by Jean Vivié, France
11. Standards Relative to Projection Halls — Work Group 6, chaired by Leslie Knopp, United Kingdom
12. Review of Program of Work

In the discussion on scope, the French delegate proposed a new version. Modifications were offered and the following scope was approved for submittal to letter ballot of TC36.

"The committee shall formulate definitions, dimensions, methods of measurement and test, and performance characteristics related to materials and apparatus used in silent and sound motion picture photography, in sound recording and reproduction and in laboratory work, also, standards relating to the installation and characteristics of projection and sound reproduction equipment.

"Collaboration is to be established with all other Technical Committees working on related questions and especially with the Committees ISO/TC 42 — Photography and ISO/TC46 — Documentation."

The previous scope is offered for comparison purposes:

"The formulation of definitions, dimensional standards, methods of test, rating and performance characteristics of materials and devices used in silent and sound motion picture photography and in sound recording and processing and reproduction in connection therewith. Collaboration is to be established with other Technical Committees, especially with ISO/TC46 — Documentation, in work on photographic reproduction."

After providing each member nation an opportunity to make a general statement on agenda items 6–11, the chairman appointed Work Group chairmen and the remainder of the sessions were devoted primarily to the detailed considerations of the six Work Groups. The conclusions reached in each Group are presented below.

Dimensions of Raw Stock

It was unanimously agreed to recommend to ISO/TC36 that the secretariat prepare a Draft ISO Proposal for letter ballot action of all members on Cutting and Perforating Dimensions for 35mm Motion Picture Positive Raw Stock to be based upon the American Standard Z22.36-1947 with the changes indicated below.

(1) Dimension A to read
$1.378 \pm^{0.000}_{0.002}$ inch $35.00 \pm^{0.00}_{0.05}$ mm

(2) Dimension L to read
18.70 ± 0.15 inch 475.00 ± 0.40 mm

(3) Dimension R to read
0.50 millimeter, provided that the secretariat finds that this is the proper way to express correspondence with 0.020 inch.

(4) Dimension G to be expressed as shown in the French Standard NFS 24-003 with the drawing of the type given therein but with the format altered to show lines referring to bottom edges of perforations rather than center lines.

(5) The footnotes in Z22.36-1947 indicated by an asterisk and a dagger, and the appendix, are to be deleted.

(6) Dimension symbol "I" to be changed to "F."

It was also unanimously agreed to recommend to ISO/TC36 that the secretariat prepare two Draft ISO Proposals on Cutting and Perforating Dimensions for 16mm Silent and Sound Motion Picture Negative and Positive Raw Stock, based upon the American Standards Z22.5-1947 and Z22.12-1947, with the following changes:

(1) Dimension A to read
0.628 ± 0.001 inch $15.95 \pm^{0.03}_{0.02}$ mm

(2) The drawing used to show dimension G in Z22.5 to follow French practice paralleling the 35mm presentation adopted from the French Standard NFS 24-003, Dimensions of 35mm Positive Raw Stock, With Positive Perforations.

(3) Dimension symbol "I" to be changed to "F" in Z22.5.

(4) Omit notes indicated by asterisk and dagger.

(5) Omit appendix.
(6) Add a new note reading
"Experience shows that it is common for film to expand when exposed to high relative humidity. Allowance should be made for this factor in equipment design and in no case should the equipment design fail to accommodate film width of 0.630 inch, 16.00 mm."

A specification for film thickness was discussed by the working group but no agreement was reached. The matter was left for further discussion and study.

Definition of Safety Film

It was initially agreed that an international standard for the definition, test and identification of safety film should be established.

One of the U.S.A. delegates believed it would be desirable that any ISO standard for 32mm, 16mm and 8mm motion picture film should stipulate the use of a safety base only. The proposal appeared to raise national statutory and legal questions which would call for investigation and consideration.

The working group noted that the research which had been conducted in the United Kingdom had established a simple form of test which might replace the more elaborate laboratory tests of the current American Standard Definition for Motion Picture Safety Film, Z22.31-1946. A demonstration of the apparatus was given and the members thought the United Kingdom test worthy of study. The United Kingdom undertook to prepare and circulate working drawings and particulars to enable each country to make its own apparatus and carry out confirmatory tests.

France and Germany, however, desired the earliest possible establishment of an international standard and suggested that the current American Standard, which was virtually a reproduction of the ISA proposal of 1936, should be considered for adoption by the ISO for a three-year period. While not seeing any urgent need for this, the United States representatives said they would not wish to oppose the adoption of this course. The United Kingdom delegates had no power to commit their country but only to express the view that the 1936 ISA proposal was too elaborate, was out-of-date and the time was ripe for a new specification to be formulated.

It was understood that the ISO was willing to circulate ISA proposals and recommendations which could be used nationally pending the agreement on an international standard.

Agreement was finally reached that the Definition for Motion Picture Safety Film, Z22.31-1946, be submitted to ISO/TC36 for letter ballot action.

Emulsion and Sound Record Positions in Cameras and Projectors

The working group agreed to recommend to ISO/TC36 that the secretariat prepare a Draft ISO Proposal incorporating the technical content of the American Standards listed below with the modifications indicated:

Emulsion and Sound Record Positions in Camera for 35mm Sound Motion Picture Film, Z22.2-1946,
Emulsion and Sound Record Positions in Projector for 35mm Sound Motion Picture Film, Z22.3-1946,
Delete paragraphs 2 and 3, reference to guided edge and footnote. Add identification of sound record (shaded area).

Emulsion Position in Camera for 16mm Silent Motion Picture Film, Z22.9-1946,
Emulsion Position in Projector for Direct Front Projection of 16mm Silent Motion Picture Film, Z22.10-1947,
Emulsion Position in Camera for 8mm Silent Motion Picture Film, Z22.21-1946,
Emulsion Position in Projector for Direct Front Projection of 8mm Silent

Motion Picture Film, Z22.22-1947,
Delete paragraph 2 and footnote.

Emulsion and Sound Record Positions in Camera for 16mm Sound Motion Picture Film, Z22.15-1946,
Delete paragraph 2, footnote and reference to guided edge. Also delete paragraph 3, but the technical substance of this paragraph is considered suitable for incorporation in a more suitable place. Add identification of sound record (shaded area).

With regard to Z22.16-1947, the working group decided that at present it did not seem desirable to consider this for international adoption since prints were made with the emulsion position on either side and there was little likelihood of universal acceptance of a single standard at this time.

The working group discussed at some length the question of projection speed of 24 or 25 frames per second, but did not reach any decision.

Dimensions and Locations for Sound Records and Scanning Area

Work Group 4 recommended that five American Standards be prepared by the secretariat for circulation as Draft ISO Proposals, two without change:

Z22.69-1948, Sound Records and Scanning Area of Double-Width Push-Pull Sound Prints, Normal Centerline Type,
Z22.70-1948, Sound Records and Scanning Area of Double-Width Push-Pull Sound Prints, Offset Centerline Type;

and three with the modifications indicated below:

Z22.40-1950, Dimensions and Locations for Sound Records and Scanning Area of 35mm Sound Motion Picture Prints
(1) The distance from the edge of the film to the centerline of the sound record shall be changed from 6.17 ± 0.02 mm to 6.19 ± 0.02 mm (0.244 ± 0.001 in.).
(2) The distance from the edge of the film to the inner edge of the printed area shall be changed from 7.75 ± 0.05 mm to 7.83 ± 0.05 mm (0.308 ± 0.002 in.). (This change was proposed by the French delegate on the basis that difficulties are being experienced in France with a white line between sound track and picture printed areas. The United Kingdom delegation reserved judgment on the dimension in (1) and (2) above, but approves the circulation of the draft.)
(3) In the specification "Distance between sound and corresponding picture" change "20 ± ½ frames" to "21 frames ± ½ frame." (When the distance from the center of the projector gate to the sound scanning point is 20 frames, the picture and sound will be in synchronism for an observer at a distance of 50 feet, and with French practice, which is based on a measured distance of 21 frames between picture and sound on the film itself, and therefore allows for synchronizing the picture to suit an average audience size.)
(4) Delete the third footnote.
(5) Delete the dimension and all reference to the height of the scanned area.

Z22.41-1946, Sound Records and Scanning Area of 16mm Sound Motion Picture Prints
(1) Change the tolerance on the width of the sound record for full width variable-density record from 0.080 ± 0.001 in. to $0.080 \begin{smallmatrix} +0.004 \\ -0.001 \end{smallmatrix}$ in.
(2) Delete the present footnote.
(3) Add a new footnote reading: "The width of the 16mm sound record is derived by reducing the corresponding 35mm dimensions by a ratio of 1.2 to 1.0 in.
(4) Add a new paragraph: "Distance between sound and corresponding picture — the sound record shall pre-

cede the center of the corresponding picture by a distance of 26 frames ± ½ frame."

PH22.86, Dimensions for 200-Mil Magnetic Sound Tracks on 35mm and 17½mm Motion Picture Film (a Proposal well on its way to becoming an American Standard).

(1) Revise the drawing and dimensions to show a dimension from the outer edge of the sound record area to the edge of the film 6.0 ± 0.05 mm (0.236 ± 0.002 in.) on each edge of the film, and delete all other dimensions and all reference to the track in the center of the film, renumbering Track 3 to Track 2. (The United Kingdom delegation was unable to associate itself fully with this resolution as being the best solution of the current practices in America, France and in the United Kingdom, and offered alternative proposals (which, however, were not accepted) on the dimension of 0.345 inch ± 0.005 or 0.345 inch ± 0.006, as the location of the centerline of the sound record relative to the edge of the film.)

(2) Delete paragraph 7.

(3) Add a note to Paragraph 6: "When the film is turned end for end, Track 2 occupies the position of Track 1."

Location and Size of Picture Apertures in Cameras, Projectors and Printers

The chairman of Group 5 has not as yet submitted the report of the conclusions reached by his group. This information will be published in a future issue of the *Journal* as soon as it is received.

Standards Relating to Projection Halls

The members of Work Group 6 had each presented at their meeting a summary of the requirements and values in their published and draft standards on the subject of screen brightness. Reference was also made to the resolution of the CIE (International Commission on Illumination) at its meeting in Stockholm in 1951. It was agreed to restrict discussion to enclosed cinema auditoriums.

The members noted that the various countries were now giving consideration to such factors as: the screen brightness measurement made from any seat in the auditorium, the diversity of luminance between the side and center of the screen, interference of luminance by stray light, the method of measurement and the type of instruments to be used. The views of the delegates on these questions were diverse and in some of the countries research and investigation were still proceeding.

Differing opinions were also expressed as to the desirability of adopting the luminance range and the diversity factors of the CIE Stockholm meeting. It was noted that the United States and the United Kingdom expressed their luminance values in foot-Lamberts while France, Germany and the CIE resolution expressed values in metric units. It was also noted that, notwithstanding these divergencies, the quantitative difference in the various specifications and in the CIE resolution were not great.

In view of the research and investigation still proceeding in the various countries, it was the general consensus that it was not opportune at the present ISO/TC36 meeting to attempt to draft an ISO proposal. It was agreed, therefore, that each country should proceed with its own investigations and revision of its own standards, if desired, and that there should be a postal exchange of information between the countries, so that at the next meeting of ISO/TC36 the present discussions might be resumed and an ISO proposal drafted.

The working group regretted that time did not permit any discussion on the remaining subjects such as projection rooms and projection screens listed under item 11 of the agenda.

Organization of the San Francisco Subsection

This brief outline of the organization of the San Francisco Subsection of the Society may be of interest and assistance to similarly situated groups in other localities.

The San Francisco Subsection began as the expression of a desire of a number of the individual members in the Bay Area to have some form of local activity and participation in the affairs of the Society. The Conventions held alternately in Hollywood provided some advantage but in general most of the members gained from their membership only the published *Journal*.

Many informal discussions had been held during 1951 regarding the practicability of setting up some form of local group and these culminated in the formation of the present organization. Edwin W. Templin and Dr. Charles R. Daily were particularly helpful in presenting our plan to the Board of Governors and securing its approval. The Constitution of the Society does not specifically provide for subsection organization but neither does it forbid it, and, by the latter liberal view, the San Francisco group was authorized to form the subsection of the Pacific Coast Section at the meeting of October 13, 1951.

Upon receiving formal notice of this action, all of the members of the Society residing in the Bay Area were notified by mail and the organizational meeting of the subsection was held November 30, 1951. Dr. Daily addressed the group at this meeting and acted as chairman, representing the parent section. Election of officers resulted in the following roster for 1952:

Chairman, Paul A. Williams
Vice-Chairman, William A. Palmer
Secretary-Treasurer, George Mathiesen
Program Chairman, John B. Steiger

During the first half of the year the subsection has held three meetings, the programs of which were as follows:

February 21: "Production of a Pilot Kinescope for the *Standard Hour*" presented by a panel consisting of Warren Andersen, A. F. Michaelis and W. A. Palmer.

April 17: "TV Picture Sizes," a tape recording of papers and discussion from a meeting of the Pacific Coast Section in Hollywood.

May 22: "Creative Directions in Color Photography" presented by Ralph Evans of Eastman Kodak Company.

Attendance at these meetings has been from 20 to 50, which, although perhaps not too impressive, represents a large percentage of the total group membership.

Although there was no expressed plan of suspending meetings during the summer, the usual circumstances have conspired to prevent or delay the fulfillment of our anticipated plans. Meetings are planned for the fall and winter and we hope to end the first year of operation at a peak of activity.

The effect of an actively functioning local group on membership recruiting activity has been very gratifying. It is conservatively estimated that we have added twice the number of new members since beginning local operation compared with the previous like period. It is also interesting to note that, although the present interest in the television field has probably encouraged activity and increased our local membership, there has been enthusiastic interest among members in the motion picture industry.

Whether or not the time is ripe for the San Francisco group to plan on an early change to independent section operation cannot yet be determined. At the end of this year officers will be elected for the coming term and that question fully discussed.

We have not been as active as we had hoped but we are certain that our activity will increase rather than diminish. It would be a real help if more assistance could be provided in securing program material. The experiment we made with the use of tape recorded material was considered successful but for some reason or another we have had some difficulty in arranging for additional recorded program material. It is noted that the IRE Audio Group has set up a similar plan with a

central tape exchange and this method might be worth consideration.

The Subsection expenses are a very minor consideration, for, aside from the cost of mailing program announcements, no other expense has been incurred. The parent Section advanced a sum sufficient to cover this and other incidental expense. Meeting places, projection or reproduction equipment and preparation of meeting notices have been provided by various members through the courtesy of their business connections.

We are firmly of the opinion that the Society as a whole and its individual members have much to gain by establishment of other subsections. The time has long since passed when New York and Hollywood represented a concentration of motion picture and television activity to the exclusion of all other areas. The Society should provide some service to its members in other areas beyond the publication and distribution of its *Journal* and we are of the opinion that the organization plan we have followed provides a means toward that end. — *Paul A. Williams*, 341 Hazelwood Ave., San Francisco 12, Calif.

Book Review

Color in Business, Science and Industry

By Deane B. Judd. Published (1952) by John Wiley, 440 Fourth Ave., New York 16. 401 pp. 106 illus. 6 × 9¼ in. Price $6.50.

Here is a most useful and valuable book by Dr. Deane B. Judd, Chief of the Colorimetry Unit of the National Bureau of Standards. During his twenty years with the Bureau he has come in contact with hundreds of industrial colorimetric problems. This book reflects his great experience along these lines as well as the many contributions which Dr. Judd has made to the science of color. It is an ambitious undertaking to attempt a book on color that would appeal to business, to science, and to industry; but through Dr. Judd's long association with all three groups he has succeeded remarkably well.

The businessman may enjoy the very readable Part I with its emphasis on the eye, the customer, and what the customer sees. He may then profit by scrutinizing the excellent introductions and summaries in each of the other sections in the remainder of the book, leaving the study of the technical details in these sections to others. However, industrial engineers and research workers in the field of color will find the entire work valuable because of the fusion of the practical problems with their theoretical aspects and the engineering or technical solutions to them. In fact, the book is mainly directed at this group, and excels any other work in telling the story of the tools and techniques available to workers in the field.

The book is divided into three parts. Basic facts pertaining to the science of color are given in Part I. Here the author explains the functioning of the eye, the characteristics and effects of abnormal vision, the methods of color matching, and the aspects of color. It is clearly shown that perception of color bridges many sciences. This is, however, treated in practical fashion as shown by the section titles: "Chemical — Pigments and Dyes," "Physical — Radiant Energy in the Spectrum," "Psychological — The Customer's Angle," and "Psychophysical — How to Predict What the Average Customer Will See."

Part II, entitled "Tools and Techniques," comprises by far the largest portion of the book. Here are set down the principles and practices for spectrophotometry, colorimetry and colorimeters, reproduction of pictures in color, color standards, uniform color scales, and color languages. Some 130 pages are devoted to these last three. He gives an unusually fine presentation with clear explanations and evaluations of available sets of color standards for specifying or matching color, such as the Munsell Book of Color, the Villalobos Colour Atlas, the Color Harmony Manual, and other systems. Color

cards or standards provided by various segments of industry such as the textile, printing ink, or paint industries, are also described. The glossary of color terms at the end of Part II will be most useful in that it collects in one place the terms and definitions for the most important color concepts used in American industry.

Part III, "The Physics and Psychophysics of Colorant Layers," thoroughly explores techniques for determining or forecasting the gloss and opacity or hiding power of colored layers. The major portion of this part is given over to the Kubelka-Munk analysis as applied to dyed textiles, paints, papers or pigmented plastics. Several mathematical tables necessary for such analytical solutions are included in the appendix which should prove useful to those interested in these materials.

There is an excellent selection of references which includes the important work in the field for those who will wish to pursue the subject further, and also a fine index.

Members of the SMPTE may be particularly interested in the section entitled "Reproductions of Pictures in Color," in which Dr. Judd outlines the general problem and also demonstrates by a practical example the use of the CIE tristimulus values and the color triangle to select practical working primaries, and thence to the determination of camera sensitivities for a typical color television system. This reviewer was particularly impressed by Dr. Judd's reasonable approach to the old question of the importance of art versus science in color reproduction. To quote:

"An important question in reproduction of pictures in color is color fidelity — how faithfully the colors of the original scene are reproduced. This is not the whole of the problem of producing pictures that the public will like. We know too little about what makes us see objects and people from the mosaic of colored patches presented to the eye from real scenes to state with confidence that a completely faithful reproduction (not yet achieved, by the way) would always look good. In fact, there are some who take the position that perfect color fidelity usually leads to poor pictures and should be avoided on purpose. They say that intentional systematic deviations from fidelity can make the picture better than the original itself. This is adding art to science. But even if you intend to try to improve on the original scene, it is a great help to have a faithful reproduction to start with. You could not get very far with intentional improvements if the basic color fidelity of the picture was so poor that it would not yield any reds, for example, in the picture, or so poor that greens in the original scene were rendered as reds in the picture. So, reasonably faithful reproduction of colors must be built into any reproduction system, even if the final aim is to improve artistically upon the original scene by intentional deviations from color fidelity."

With the increasing emphasis on color in motion pictures and television, an understanding of this concept is important.

This book is highly recommended to all interested in color and its industrial applications.—*L. M. Dearing*, Technicolor Motion Picture Corp., 6311 Romaine St., Hollywood 38, Calif.

Journal on Microfilm

Microfilm editions of the *Journal* of the SMPTE are now available to members and subscribers from University Microfilms, Ann Arbor, Mich., which records more than 700 periodicals. *Journal* Volumes 54 and 55 (1950) are priced at $4.15 and Volumes 56 and 57 (1951) cost $4.00 (this is the year that the *Journal* switched to the two-column format, with a saving in pages). If there were enough demand for it, University Microfilms would make positives for the years 1941–49. The present price for such positives is about a half cent per page, but this would be reduced with a larger number of customers to share the cost of the negatives. Readers may address inquiries to University Microfilms, 313 North First St., Ann Arbor, Mich.

Members and the Journal Overseas

Echoes of the impact of the SMPTE and the *Journal* come back to us from overseas now and then — and we should record them, just as we have been able earlier in this *Journal* to record the exchange of bases for international standardization.

A recent letter from Vernon Jarratt, Manager of Mole-Richardson (Italia), Rome, prompts some quotation and notation about the Society in Italy:

"What I have noticed is the considerable increase in the circulation of the *Journal* in the three years that I have been a member. This is probably more noticeable to someone like myself who is in constant touch with the various technical heads than visible in your list of subscriptions, as a good deal of the 'circulation' is the literal circulation of a copy that travels from office to office and from desk to desk.

"When Mole-Richardson opened here in 1948 the technical side of the industry was in a pretty primitive state all around, as indeed is obvious to anybody who, from a purely technical point of view, considers the films such as *Rome Open City*, *Four Steps in the Clouds*, *Paisà*, and the other films with which Italy first made its postwar name. This was partly due to destruction and looting during the war, and partly to the Fascist policy of autarchy which threw the Italian industry very much back on its own resources.

"One incidental result of this was rather amusing. When we brought in the first 'Brutes' in 1949 most cameramen refused to touch them, insisting that they could manage quite well with the 150-amp arcs to which they were already accustomed. One or two of the more enterprising (who, incidentally and not surprisingly, are also members of the Society) broke the ice, however, and the rest rapidly followed. The difference was very noticeable when, last year, we introduced Compact Source (mercury-cadmium) equipment for the first time. Although this represents a much bigger technical difference from previously existing equipment than the Brute, which is after all only a larger carbon arc, the Compact Source equipment was accepted with much less resistance. Now, and thanks certainly in part to the *Journal*, there is a much livelier interest in technical developments."

Mr. Jarratt's letter prompted a few moments research which revealed the following thirteen members with addresses in Italy.

Baume, Alessio, Manager, 16mm, Metro-Goldwyn-Mayer, Italy. **Mail:** Via Camilluccia 71, Roma, Italy. **(A, 1947)**

Carrara, Enrico, Vice-President, Cetra Records, Corso Pesihiera 10, Torino, Italy. **(A, 1949)**

Cambi, Enzo, Consulting Engineer, Cinecitta Studios; Lecturer, National Research Council (Italy) and Leghorn Naval Academy. **Mail:** Via Giovanni Antonelli 3, Rome, Italy. **(A, 1950)**

Corradi, Amerigo, Tecnostampa, Via Albalonga 38, Rome, Italy. **(A, 1950)**

Dalle Rose, Demetrio D., Manager, Western Electric Company of Italy, Inc. **Mail:** Via Oglio 9, Rome, Italy. **(A, 1946)**

De Renzis, Francesco, Manager, Westrex Co. (Italy), Piazza Lovatelli 1, Rome, Italy. **(A, 1945)**

Innamorati, Libero, Dr. Ing., Centro Sperimentace Cinemato-Grafia. **Mail:** Via Satrico 43, Rome, Italy. **(A, 1936)**

Jarratt, C. V., Manager, Mole-Richardson (Italia), Via Dell'Arco Di Travertino, No. 57, Rome, Italy. **(A, 1949)**

Marzari, Antonio, Cameraman, Shorts Producer and Director, Veneziana Cortometraggi, S. Marcd 557, Venice, Italy. **(A, 1947)**

Monteleoni, Giulio Cesare, Ispettore Tecnico, Soc. Ferrania. **Mail:** Via Crispi 10, Rome, Italy. **(A, 1948)**

Portalupi, Piero, Director of Photography in Motion Picture Production, Lux Film. **Mail:** Viale Bruno Buozzi 83 int F, Rome, Italy. **(M, 1952)**

Robecchi, Franco, Sound Engineer, Titanus. **Mail:** Piazzale Metronio 1, Rome, Italy. **(A, 1948)**

Trentino, Victor, Motion Picture Sound Engineer, 2 Via Ipponi, Rome, Italy. **(A, 1945)**

Zambuto, Mauro, Technical Director, Scalera Films. **Mail:** Italian Films Export, 1501 Broadway, New York 36, N.Y. **(M, 1952)**

Obituary

Nathan Levinson died on October 18 at his home in Hollywood. He was 64. He was head of Warner Brothers sound department and well known for his work in the early days of sound motion pictures. He was credited, with the late Samuel L. Warner, with responsibility for the first sound film projection which was the musical score for *Don Juan* exhibited in New York in August 1926. Voice reproduction followed in 1927 with the release by Warner Brothers' Vitaphone Corp. of Al Jolson's *The Jazz Singer*.

Born in New York City he was early at work as a Western Union messenger. After learning telegraphy "on his own," Nathan Levinson became a civilian radio engineer with Marconi and for the Navy. World War I found him a Signal Corps Major in command of the Fort Monmouth, N.J., Laboratories. In the early twenties he was a commercial engineer in the radio broadcast field for the Western Electric Co. on the Pacific Coast and in 1925 he was managing director of San Francisco's radio station KPO. A year later he was Warner Brothers' sound director and western division manager of Vitaphone Corp.

Col. Levinson was a Fellow of this Society and most recently served as a member of the Theater Television Committee. He was awarded the Society's Samuel L. Warner Memorial Medal in 1948 "for his outstanding work in the field of motion picture sound recording, the intercutting of variable-area and variable-density sound tracks, the commercial use of control track for extending volume range, and the use of the first sound-proof camera blimps."

He was interested and instrumental in a variety of developments. For instance, the use of 16mm motion pictures with high-speed development, while not an original idea with Col. Levinson, was, under his guidance, commercialized for recording race-track events. During World War II the Navy asked Warner Brothers to take over the manufacture of a special combat camera and responsibility for it was added to Col. Levinson's direction of Warner Brothers' sound department. He was a Warner Brothers' representative on the Research Council for the past twenty years. In 1941, Col. Levinson was given a special award by the Academy of Motion Picture Arts and Sciences for "outstanding service to the industry and to the Army." The next year he received the Academy Award for the best sound recording, that of *Yankee Doodle Dandy*.

SMPTE Lapel Pins

The Society will have available for mailing after September 15, 1952, its gold and blue enamel lapel pin, with a screw back. The pin is a ½-in. reproduction of the Society symbol — the film, sprocket and television tube — which appears on the *Journal* cover.

The price of the pin is $4.00, including Federal Tax; in New York City, add 3% sales tax.

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1952 MEMBERSHIP DIRECTORY.

Honorary (H) Fellow (F) Active (M) Associate (A) Student (S)

Appleby, Fredericka, New York University. **Mail:** 810 Broadway, Newark, N.J. (S)

Bell, Charles L., Supervisor of Production (East Coast), The Jam Handy Organization, 1775 Broadway, Rm. 407, New York 19, N.Y. (A)

Birdno, George M., TV Engineer, National Broadcasting Co. **Mail:** 11028 Moorpark St., North Hollywood, Calif. (A)

Bowman, Lester H., Director of Technical Operations, CBS-KNX-KNXT, Columbia Broadcasting System, Inc., 6121 Sunset Blvd., Hollywood 28, Calif. (M)

Brooke, Ned R., Film Director, WSAZ-TV, West Virginia Bldg., Huntington, W. Va. (A)

Brunswick, Lawrence F., Optical Engineer, Colorvision, Inc. **Mail:** 11190 Valley Spring Pl., North Hollywood, Calif. (M)

Burton, John W., Motion Picture Photographer, Engineer, U.S. Navy, 11th Division, Naval Air Station, Anacostia 20, D.C. (A)

Butler, Elliott H., City College, Film Inst. **Mail:** 470 Audubon Ave., New York 33, N.Y. (S)

Cannella, Ben R., Cameraman, Picture House, Inc. **Mail:** c/o Reta Jensen, Mountain, Wis. (A)

Challacombe, Jack A., Foreman, Sensitometric Control Dept., Cinecolor Corp., 2800 W. Olive, Burbank, Calif. (A)

Chullasapya, Brig. Gen. Dawee, Royal Thai Air Force, Bangkok, Thailand. (M)

Cochran, Lee W., Director, Bureau of Audio-Visual Instruction, State University of Iowa, Iowa City, Iowa. (M)

Connor, Roland E., Equipment Engineer, Eastman Kodak Co. **Mail:** 16 Lilac Dr., Rochester, N.Y. (M)

Cotlov, Nelson, Projectionist, South City Drive-In; Film Editor, Capital Film Exchange. **Mail:** 819 Parmley Ave., Yeadon, Pa. (A)

Craig, Stephen R., Motion Picture Sound Engineer, Great Commission Films, Inc. **Mail:** 3455 Meier St., Venice, Calif. (A)

de Forest, Allan F., Manager, Special Services, Peerless Film Processing Corp. **Mail:** 11 Bank St., New York, N.Y. (A)

Embree, Lee R., Motion Picture Photographer, U.S. Air Force. **Mail:** 265 E. Montecito Ave., Sierra Madre, Calif. (A)

Fernandez, R., Carlos, Sound and Theater Engineer, J. Glottmann S.A. **Mail:** Carrera 19, #47-23, Bogota, Colombia. (M)

Foy, Walter L., Chemist, E. I. du Pont de Nemours & Co. **Mail:** 78 Van Liew Ave., Milltown, N.J. (M)

Grunwald, Robert, President, Harwald Co., Inc., 1261 Chicago Ave., Evanston, Ill. (A)

Hann, William G., Film Technician, Cinecolor Corp. **Mail:** 11626 Chandler Blvd., North Hollywood, Calif. (A)

Harris, Franklin S., Jr., Physicist, Department of Physics, University of Utah, Salt Lake City 1, Utah. (M)

Hauser, Willard H., Chief Engineer, WBL-TV, Westinghouse Radio Stations, Inc., 1170 Soldiers Field Rd., Lexington, Mass. (M)

Howell, Joseph E., Chief Engineer, WDSC. **Mail:** 604 Carthage Rd., Lumberton, N.C. (A)

Hubbard, Ray A., Art Director, KPIX. **Mail:** 74 Alta Vista, Mill Valley, Calif. (M)

Izquierdo, Mike, Sound Engineer, Cines Alcazar S.A. (International Amusement Co.). **Mail:** 7539 Taxco Rd., El Paso, Tex. (A)

Jackson, Robert M., Animation Photographer, The Calvin Co. **Mail:** 4117 Mercier St., Kansas City 2, Mo. (A)

Jackson, William J., Chief Engineer, KEYL, San Antonio Television Co., Transit Tower, San Antonio, Tex. (M)

Jewell, James, Television Engineer, Motion Picture Cameraman, WWJ-TV. **Mail:** 26191 Allen Rd., Trenton, Mich. (M)

Jost, Hans Joachim, Albrechtstrasse, 78, Berlin-Steglitz, Germany. (M)

Kaak, Henry W., Jr., Assistant Technical Adviser, Camera Dept., Technicolor Motion Picture Corp. **Mail:** 7745 Agnes Ave., North Hollywood, Calif. (A)

Kelly, Michael, Motion Picture Cameraman, Northrop Aircraft Co. **Mail:** 6109¼ Victoria Ave., Los Angeles 43, Calif. (M)

Klein, Max R., Director, Army Film Library Services, U.S. Army (Civ. Service). **Mail:** 1387 Linden Ave., Highland Park, Ill. (M)

Kraus, Robert W., Apprentice, Motion Picture Laboratory Technician, Precision Film Laboratories. **Mail:** 2006 Benson Ave., Brooklyn, 14, N.Y. (A)

Kuriyama, Tetsuzo, Managing Director, Nippon Onkyo Seiki Co. (Japan Sound Equipment). **Mail:** c/o R. A. Haines, FEC Motion Picture Div., Special Services Section, GHQ, Far East Command, APO 500, c/o P.M., San Francisco, Calif. (A)

Laeser, Phillip B., Television and Radio Engineer, The Journal Co., WTMJ-TV, 720 E. Capitol Dr., Milwaukee, Wis. (M)

Lapins, Theodore, Engineer, H. de Lanauze Cinema Distribution & Service. **Mail:** Isle Perrot, Terrace, Quebec, Canada. (A)

Lewis, Earl W., Radio-Television Engineer, WTVJ. **Mail:** 795 Harbor Dr., Key Biscayne, Miami 49, Fla. (M)

Lewis, J. Kenneth, Recording Engineer, U.S. Navy Dept., Bureau of Ships. **Mail:** 9209 48 Ave., College Park, Md. (A)

Lorenc, Richard M., Electronics Text Development Draftsman, De Forest's Training, Inc. **Mail:** 6925 W. Highland Ave., Chicago 31, Ill. (A)

Lotz, H. Walter, Factory Superintendent, Motiograph, Inc., 4431 W. Lake St., Chicago 24, Ill. (M)

Love, Nathan, Superintendent Technician, Federal Engineering Co. **Mail:** 376 E. Eighth St., Brooklyn 18, N.Y. (A)

Mejid, Kerim, Motion Picture Cameraman, Ministry of Education (Iraq). **Mail:** Audio-Visual Center, 121 College Pl., Syracuse, N.Y. (A)

Metzger, William H., Motion Picture Technician, Ansco, Div. Gen'l Aniline & Film Corp., 405 Lexington Ave., New York, N.Y. (A)

Obata, Toshikazu, Director, Dentsu Motion Picture Co. **Mail:** 104 Mukoyama-Cho, Nerima-Ku, Tokyo, Japan. (A)

Oliver, Francis A., Sound Engineer, American Broadcasting Co. **Mail:** 129 S. Manhattan Pl., Los Angeles 4, Calif. (M)

Palenzuela, Carlos V., Sound Engineer, Westrex Corp. (Asia). **Mail:** 418 Sta. Mesa St., Manila, Philippines. (A)

Petersen, Ernest L., Engineering Coordinator, Electronics Lab., Northrop Aircraft, Inc. **Mail:** 5205 Calderwood St., Long Beach 4, Calif. (A)

Ramos, Augusto B., Technical Department Manager, Philips Portuguesa S.A.R.L. **Mail:** Rua do Telhal, 71-1°-E., Lisbon, Portugal. (A)

Ratcher, Mohammed E., 111 E. 26 St., New York 10, N.Y. (A)

Roberts, Warren S., High-Speed Motion Picture Photographer, Sandia Corp. **Mail:** 2442 La Vetz Dr., N.E., Albuquerque, N.M. (A)

Schock, William R., Television Engineer, KEYL, San Antonio Television Co. **Mail:** 302 Freiling Dr., San Antonio 1A, Tex. (A)

Schuller, Edgar A., Motion Picture Sound Recording, U.S. Army Signal Corps. **Mail:** 30-32 — 50 St., Woodside, L.I., N.Y. (A)

Schutz, George, Editor, Quigley Publishing Co., RKO Bldg., Rockefeller Center, New York 20, N.Y. (M)

Selzer, Robert H., University of California at Los Angeles. **Mail:** 112 N. Highland Ave., Los Angeles 36, Calif. (S)

Sessions, Stanley H., Sound Technician, U.S. Navy Electronics Laboratory. **Mail:** 1886 Malden St., San Diego 9, Calif. (A)

Sombor, Harry, Chief Engineer, Sound Dept., Studio Films, Inc. **Mail:** 1498 Addison Rd., Cleveland, Ohio. (M)

Speed, Richard L., TV Technician, KPIX. **Mail:** 14 Ricardo La., Mill Valley, Calif. (A)

Stainton, Walter H., Cornell University, Goldwin Smith Hall, Ithaca, N.Y. (A)

Stevenson, Paul J., 2231 N. 12 St., Phoenix, Ariz. (S)

Swanell, Lt. Edward F., Motion Picture Officer, Film Editor, U.S. Air Force, 1st Photographic Sqdn., AP&CS, 200 King St., Alexandria, Va. (M)

Vittum, Paul W., Chemist, Research Supervisor, Eastman Kodak Co., Kodak Park Works, Rochester 4, N.Y. (M)

Warndorf, Lt. Col. J. P., Chief, Tech. Photo Service Br., Support Div., Wright Air Development Center. **Mail:** 3817 Merrimac Ave., Dayton 5, Ohio. (M)

Watkins, James E., Engineer, Philips Laboratories, Inc., 100 E. 42 St., New York 17, N.Y. (M)

Yoshisaka, Kiyoji, Managing Director, Tokyo Theatre Supply Co., Ltd. **Mail:** c/o R. A. Haines, FEC Motion Picture Div., Special Services Section, GHQ, Far East Command, APO 500, c/o P.M., San Francisco, Calif. (A)

Youngman, John E., Print Foreman, Telefilms, Inc. **Mail:** 4220 McFarlane Ave., Burbank, Calif. (A)

CHANGES IN GRADE

Arnold, John, (M) to (F)
Blake, E. E., (M) to (F)
Cooke, Norman C., (S) to (A)
Dupy, Olin L., (M) to (F)
Freund, Karl, (M) to (F)
Gregory, John R., (S) to (A)
Gretener, Edgar, (M) to (F)
Hanson, W. T., Jr., (M) to (F)
Heppberger, C. E., (M) to (F)
Hood, Henry J., (M) to (F)
Ireland, R. Paul, (A) to (M)
Jensen, A. G., (M) to (F)
Landsberg, Klaus, (M) to (F)
Lawrence, C. Richmond, (S) to (A)
Perkins, Carleton S., (A) to (M)
Reichard, E. H., (M) to (F)
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Stott, John G., (M) to (F)
Templin, E. W., (M) to (F)
Thulin, Einar, Jr., (S) to (A)

Position Wanted

TV Producer-Director: Now Chief of Production in Army's first mobile TV system; military experience in writing-directing high-speed, low-cost instructional productions; formerly TV producer-director, KRON-TV San Francisco, five shows weekly; will be separated from service Nov. 1952; desire connection in educational TV, preferably employing kinescope techniques; married; prefer West Coast, but willing to travel; résumé, script samples, pictures of work — on request; 1st Lt. Robert Lownsbery, SigC Mbl TV Sys, c/o Sig Photo Center, 35-11 35th Ave., Long Island City 1, N.Y.

Journals Available and Wanted

Available

Upon a reasonable offer to Alfred S. Norbury, 3526 Harrison St., Kansas City 3, Mo.:

Vol. 44 (Jan.-June 1945)
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Vol. 49 (July-Dec. 1947)
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Vol. 51 (July-Dec. 1948)
Vol. 52 (Jan.-June 1949)
Vol. 56 (Jan.-June 1951)
Vol. 57 (July-Dec. 1951)

A set of Journals from January 1945 through 1951 at $15.00 plus packing and carrying costs from Richard W. Maedler, 32–52 — 46 St., Long Island City 3, N.Y.

Complete set, in excellent condition, from January 1930 to date, plus one issue of September 1928 from Don Canady, 5125 Myerdale Drive, R.R. 15, Cincinnati 36, Ohio.

5 years (1947–51) in perfect condition plus the indexes for 1936–45 and 1946–50 and including the 1949 High-Speed Photography, upon any reasonable offer to Vic Gretzinger, 3547 Suter St., Oakland 19, Calif.

Transactions Nos. 11, 14, 20, 21, 23, 25, 27, 28 and 38; and 22 years of the *Journal* (1930–1951) except for Jan., Feb., Mar. and Apr. of 1934, Jan. and Apr. of 1948, and Feb. 1950; also these extra single copies — Nov. 1930; Jan., Feb., July and Nov. 1931; June 1932; Mar. and Apr. 1933; Dec. 1934; Jan. and May 1935; Oct. 1938; July and Dec. 1940; Oct. 1948 and Jan. 1950, upon any reasonable offer made to Paul J. Larsen, Assistant to the President, Borg-Warner Corp., 310 So. Michigan Ave., Chicago 4, Ill.

Wanted

Transactions 1, 6 and 7. Contact Mrs. Dorothy Gelatt, Henry M. Lester, 101 Park Ave., New York 17, N.Y.

High-Speed Photography, Volume 1, reprint or original Journal, March 1949, Part II, by John H. Waddell, Wollensak Optical Co., 850 Hudson Ave., Rochester 21, N.Y.

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April *Journal*.

New Products

Further information about these items can be obtained direct from the addresses given. As in the case of technical papers, the Society is not responsible for manufacturers' statements, and publication of these items does not constitute endorsement of the products.

Aluminized mirrors specifically designed for Schlieren observation and photography are now available from J. A. Maurer, Inc., Photographic Instrumentation Div., 37–01 31st St., Long Island City 1, N.Y. The Schlieren technique is being widely applied to such studies as air and gas flow, aerodynamics, ballistics, and combustion, permitting visualization and qualitative and quantitative analysis. These mirrors, manufactured by Optical Works Limited of London, England, are available in a number of standard sizes from 4 in. to 18 in. in diameter. Both spherical and plane mirrors are included in this series, with the spherical mirrors available in various focal lengths. These mirrors are manufactured to the highest practical optical precision and are mounted in precise mechanical mounts, permitting coarse and fine adjustment about the vertical and horizontal axes. Detachable metal covers are provided to protect the mirrors when not in use.

Meetings

American Institute of Electrical Engineers (Symposium on The Science of Music and Its Reproduction — 1st Lecture), Nov. 7, Engineering Societies Bldg., New York, N.Y.

Acoustical Society of America, Nov. 13–15, Balboa Park, San Diego, Calif.

American Standards Association, Annual Meeting, Nov. 19, Waldorf-Astoria, New York, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting (in conjunction with I.R.E.), Nov. 21, Western Society of Engineers, Chicago, Ill.

American Physical Society, Nov. 28–29, Washington University, St. Louis, Mo.

Society of Motion Picture and Television Engineers, Central Section Meeting (in conjunction with Society of Photographic Engineers), Dec. 3, Bell & Howell Co., Chicago, Ill.

American Institute of Chemical Engineers, Annual Meeting, Dec. 7–10, Cleveland, Ohio

American Institute of Electrical Engineers (Symposium on The Science of Music and Its Reproduction — 2d Lecture), Dec. 11, Engineering Societies Bldg., New York, N.Y.

American Institute of Electrical Engineers (Symposium on the Science of Music and Its Reproduction — 3d Lecture), Jan. 15, Engineering Societies Bldg., New York, N.Y.

Institute of Radio Engineers Conference and Electronics Show, 5th Annual Southwestern Conference and Show, Feb. 5–7, San Antonio, Texas

American Institute of Electrical Engineers (Symposium on the Science of Music and Its Reproduction — 4th Lecture), Feb. 20, Engineering Societies Bldg., New York, N.Y.

Society of Motion Picture and Television Engineers

40 West 40th Street, New York 18, N. Y., Tel. LOngacre 5-0172
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E. W. D'Arcy, 7045 No. Osceola Ave., Chicago, Ill.
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Cinecolor Corporation
Cineffects, Inc.
Geo. W. Colburn Laboratory, Inc.
Consolidated Film Industries
DeLuxe Laboratories, Inc.
De Vry Corporation
Du-Art Film Laboratories, Inc.
E. I. du Pont de Nemours & Co., Inc.
Eastman Kodak Company
Max Factor, Inc.
Federal Manufacturing and Engineering Corp.
Fordel Film Laboratories
General Electric Company
General Precision Equipment Corp.
- Ampro Corporation
- Askania Regulator Company
- General Precision Laboratory, Incorporated
- The Hertner Electric Company
- International Projector Corporation
- J. E. McAuley Mfg. Co.
- National Theatre Supply
- The Strong Electric Company

W. J. German, Inc.
Guffanti Film Laboratories, Inc.
Hunt's Theatres
Hurley Screen Company, Inc.
The Jam Handy Organization, Inc.
Kollmorgen Optical Corporation
Lorraine Carbons
March of Time
J. A. Maurer, Inc.
Mecca Film Laboratories, Inc.
Mitchell Camera Corporation
Mole-Richardson Co.
Motiograph, Inc.
Motion Picture Association of America, Inc.
- Allied Artists Productions, Inc.
- Columbia Pictures Corporation
- Loew's Inc.
- Paramount Pictures Corporation
- Republic Pictures Corp.
- RKO Radio Pictures, Inc.
- Twentieth Century-Fox Film Corp.
- Universal Pictures Company, Inc.
- Warner Bros. Pictures, Inc.

Movielab Film Laboratories, Inc.
National Carbon
National Cine Equipment, Inc.
National Screen Service Corporation
National Theaters Amusement Co., Inc.
Neighborhood Theatre, Inc.
Neumade Products Corp.
Northwest Sound Service, Inc.
Producers Service Co.
Radiant Manufacturing Corporation
Radio Corporation of America, RCA Victor Division
Reid H. Ray Film Industries, Inc.
Reeves Sound Studios, Inc.
S.O.S. Cinema Supply Corp.
SRT Television Studios
Technicolor Motion Picture Corporation
Terrytoons, Inc.
Theatre Holding Corporation
Titra Film Laboratories, Inc.
United Amusement Corp., Ltd.
Westinghouse Electric Corporation
Westrex Corporation
Wilding Picture Productions, Inc.
Wollensak Optical Company